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SQUEEZE CASTING OF STEEL WEAPON COMPONENTS

FINAL REPORT

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The project efforts described in this report demonstrate the feasibility of squeeze casting two specific steel weapon components -- the receiver base and the barrel support of the M85 Machine Gun. Squeeze casting is a hybrid of the conventional casting and forging techniques: molten metal is poured into a lower die cavity, and an upper die descends, displaces the liquid to fill the cavity, and compresses the confined molten form until solidified. This report

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details the experimental techniques developed, problems encountered techniques for their solutions, optimized parameters for squeeze casting the receiver base and barrel support, and evaluation of the products.

Project efforts relate how molten, low-carbon alloy steel is vertically displaced through adjoining tubular and flat-walled columns and squeeze cast to form the barrel support. Auxiliary ram pressure applied in the die system for squeeze casting the receiver base, independent of the main ram pressure, effectively eliminates shrinkage in the abruptly thicker, last-to-freeze sections. Squeeze casting yields (ready-to-machine weight compared to melt-charge weight) for producing radiographically sound supports and bases exceed 90 percent, whereas conventional sand mold casting yields approach 30 and 45 percent, respectively.

The most favorable components to squeeze cast have compact, symmetrical designs without more complexity than a simple U-shaped cross section. Feasible designs are limited to those components which do not require molten steel to be displaced through thin, fast-freezing sections to feed adjacent sections before squeeze pressure is applied. (D.A. Stawarz, K.M. Kulkarni, R.B. Miclot and K.R. Iyer)

FOREWORD

This report was prepared by Mr. D.A. Stawarz and Dr. K. M. Kulkarni of IITRI, Chicago, IL in compliance with Contract DAAF03-73-C0099 and by Mr. R. B. Miclot and Dr. K. R. Iyer of the Research Directorate, GEN Thomas J. Rodman Laboratory, Rock Island Arsenal, Rock Island, IL.

The work was authorized as part of the Manufacturing Methods and Technology Program of the U.S. Army Materiel Development and Readiness Command and was administered by the U.S. Army Industrial Base Engineering Activity.

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1. INTRODUCTION

The conventional casting and metal forming processes often result in oversize and heavy weapon components, which then must be extensively finish-machined. Since the machining cost is then a large fraction of the overall cost, this is an area for potential cost reduction in fabricating weapon components. In sand castings, much expense is also associated with the preparation of molds and trimming of the castings. Typical of such steel parts are a barrel support and receiver base required by the U.S. Army Armament Command, Rock Island, Illinois. In the effort to reduce cost, alternative methods of production merit investigation.

IIT Research Institute has conducted much research on squeeze casting or liquid metal forging. Basically, this process consists of metering molten metal into a bottom die cavity, allowing it to cool below the liquidus, then applying pressure by means of a top punch and allowing the solidification to go to completion under moderate pressure. As the name suggests, it is a process intermediate between conventional casting and forging and combines the advantages of both. Thus, it can be used for making parts of greater complexity than forgings and of better product quality than castings. Further, the amount of finish machining can be reduced compared to both the conventional forging and casting methods. Since squeeze casting does not need risers and gates, material yield is improved significantly. The process also eliminates mold preparation, handling and storage of sand, and associated tasks.

The primary objective of this program is to determine the applicability of the squeeze casting process to fabrication of weapon components by making two components--a barrel support and a receiver base--as squeeze castings. These are the most difficult parts ever attempted for fabrication by the squeeze casting process in view of the complexity of the barrel support geometry and the large areas of thin section thicknesses and long lengths of both components. The difficulty is enhanced greatly because the low-carbon steel from which these components are made has a high melting temperature range. These components, therefore, required the utmost from the existing squeeze casting knowledge and also necessitated substantial innovation in process design.

The project sought answers to such questions as: Can complex components be made by the squeeze casting process? What would be the area of cost saving in the overall production cost with the squeeze casting process as compared to the sand casting process currently used for these components? What are the important considerations in design and fabrication of the tooling, and how is the tool life affected by the complexity of the components? What is the influence of important process variables? Finally, it was desired to extend the experience of squeeze casting these complex components to make generalizations that would be useful in selecting other components for fabrication by the new technology.

This report summarizes the work conducted throughout the project. First, the principle of the process and its advantages are described and some published work is reviewed. Then, the geometry of the two components is discussed along with the considerations of design and fabrication of the tooling. Equipment and procedural details concerned with hydraulic press, melting and melt transfer, die heating and coating, and experimental procedure are presented briefly. The squeeze casting trials for the two components are reviewed along with the influence they had on various tooling modifications that became necessary. The squeeze castings are then evaluated in terms of surface conditions, internal structure, and mechanical properties. Factors such as part geometry and various process variables and die materials are considered, and generalizations are made as to how the applicability of the process can be considered or determined for any particular component. Preliminary process specifications are drawn for the two components, and a summary of the main accomplishments are presented.

2. TECHNICAL DISCUSSION

2.1 Squeeze Casting--Process Parameters and Advantages

The process is variously termed liquid metal forging, squeeze casting, or extrusion casting. It is essentially a hybrid of the forging and the casting processes. Much work has been conducted on the process, both in terms of research and commercial applications, in Russia for quite some time although it is a relative newcomer in this country. There are various publications discussing the major facets pertaining to the technique.[1-7]

The four stages of squeeze casting are shown in Fig. 1. They consist of metering the molten metal into the die cavity, allowing it to solidify partially, applying pressure to fill the die cavity and to accomplish solidification under pressure, and, finally, removing the completed casting from the die cavity. Initially, the molten metal is somewhat superheated, a certain time is allowed for the melt to cool in the die cavity, and during this period partial solidification takes place. In the third stage, when the dies are closed, the pressure applied displaces the metal to fill the die cavity completely and the interdendritic porosity is eliminated by pressure feeding the molten metal. The pressure is maintained

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(1) V. M. Plyatskii, Extrusion Casting, New York: Primary Sources, 1965.

(2) P. N. Bidulya, "Theoretical Principles of Squeezing Steel During Crystallization," Russian Castings Production, September 1964, pp. 396-398.

(3) V. I. Bobrov, A. I. Batyshev, and P. N. Bidulya, "Squeezing Steel Castings During Crystallization," Russian Castings Production, April 1967, pp. 153-156.

(4) K. M. Kulkarni, "Hybrid Processes Combine Casting and Forging," Machine Design, Vol. 46, No. 11, May 2, 1974, p. 125.

(5) J. C. Benedyk, "Squeeze Casting," Trans. SDCE (Society of Die Casting Engineers), 1970, Vol. 8, paper No. 86.

(6) J. C. Benedyk, "Manufacturing Possibilities with Squeeze Casting," technical paper No. CM71-840, Society of Manufacturing Engineers, 1971.

(7) J. C. Benedyk, "Squeeze Casting: Combining Forging Properties in a Large Casting," technical paper No. 72-DE-7, American Society of Mechanical Engineers, 1972.

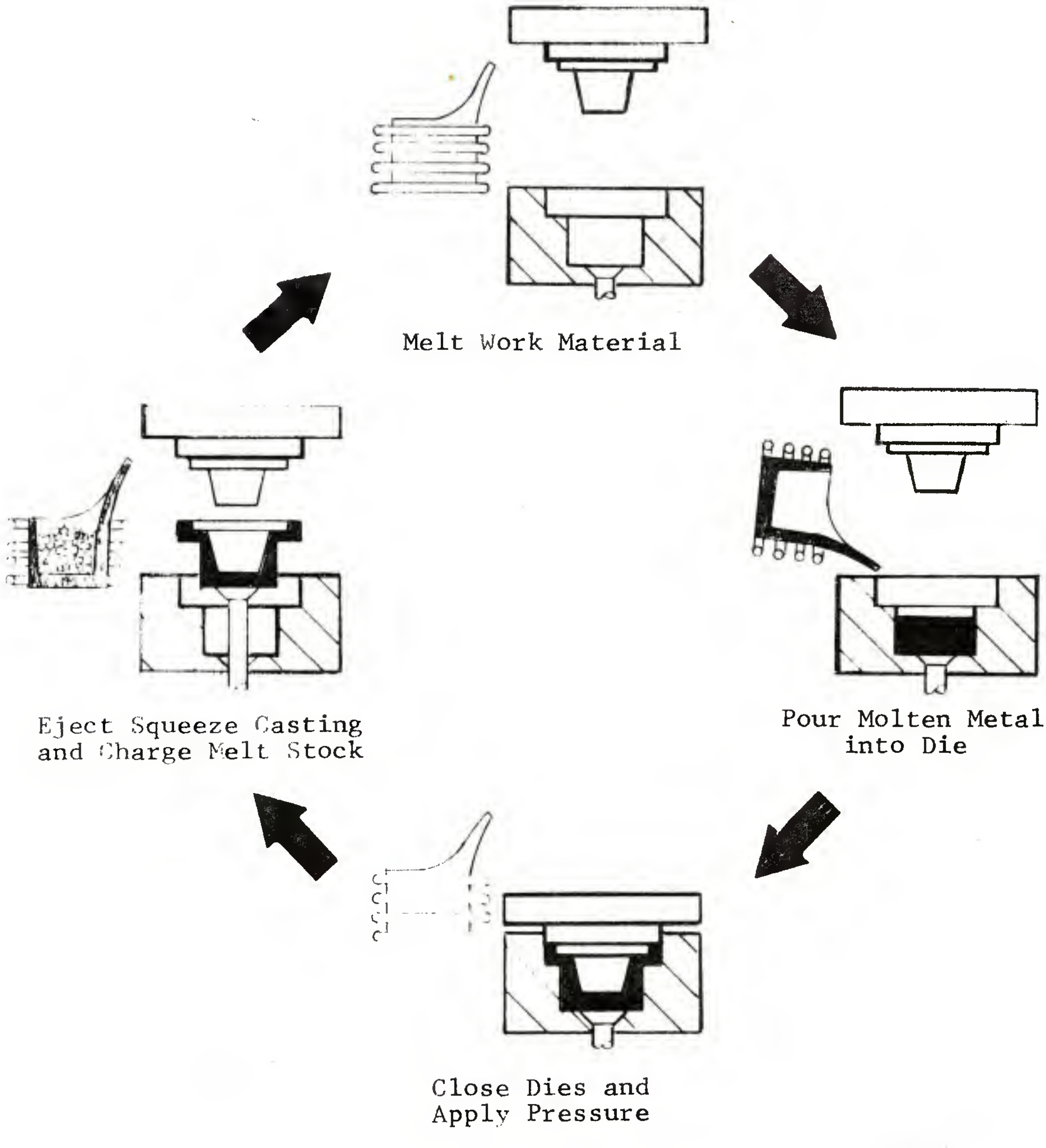

Figure 1

Production Sequence for Squeeze Casting

long enough to complete the solidification. The pressure level is high enough to eliminate all traces of shrinkage porosity and to keep any gas in solution so that the casting is completely free of porosity.

It is important to distinguish the squeeze casting process from the ferrous die casting process.[8,9] As the name suggests, the latter is essentially a die casting process in which the molten metal is forced under great pressure into the die cavities through narrow runners and gates. Although the injection pressure is high, the metal usually solidifies first at the narrow entrances to the die cavities and the metal in the die itself then solidifies under essentially atmospheric pressure. Therefore, the quality of the ferrous die castings is quite poor. Porosity at the center of the casting is quite common and, as a result, the mechanical properties of the products are also poor. There is loss of material because of the runner system needed for die casting. Additionally, the problem of die life becomes severe because of the need to push the molten steel through narrow openings. Current status of the art[8,9] allows production of only small parts weighing a few pounds at the most. Furthermore, the machines required for ferrous die casting would be expected to be very elaborate and expensive. As in any die casting process, high clamping forces will be needed to hold the two halves of the dies together against the high injection forces although the pressure during solidification of the workpiece is quite small. Considering the principles of squeeze casting and various other information discussed below, the capability of squeeze casting is far superior to that of ferrous die casting in terms of product quality, product size, and cost for the equipment.

The squeeze casting process also differs from rheocasting.(10-12) Unlike the former, the rheocasting process

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(8) "Ferrous Die Casting," compilation of reprints from industrial magazines, for General Electric.

(9) R. E. Cross, "Ferrous Die Casting," Die Casting Engineer, November-December 1971, 14 ff.

(10) R. Mehrabian and M. C. Flemings, "Die Casting of Partially Solidified Alloys," Trans. AFS, Vol. 80, 1972, pp. 173-183; Die Casting Engineer, July-August, 1973, pp. 49-59.

(11) M. C. Flemings and R. Mehrabian, "Casting Semi-Solid Metals," Transactions, International Foundry Congress, Moscow, 1973, AFS Trans., Vol. 81, pp. 81-88.

(12) M. C. Flemings, et al., "Machine Casting of Ferrous Alloys," AMMRC CTR 75-22, Interim Reports covering Contract No. DAAG46-73-C-0110 to October 1975.

involves several different steps. Basically, it consists of agitating the molten metal until approximately half the metal solidifies. Then, the semisolid material is transferred into the forming dies and subjected to the forming operation. While several advantages have been claimed for the process, as far as can be judged thus far, the work has been limited to making of small components from nonferrous materials or cast irons. Recent major efforts(11) have concerned development of tooling or equipment for various phases of rheocasting. At least so far, the process has not been applied to fabrication of complex steel components of the type that are under investigation in this program.

The main process variables in squeeze casting are the melt temperature, the time delay before the pressure is applied to the solidifying material, the pressure level and its duration, and the tooling temperature. The melt temperature should be kept low to get good die life, but it should be high enough to give a good surface finish and internal quality to the product. The time delay should be such that the pressure is applied on the partially solidified material and not while it is still completely molten. In large components, especially of nonferrous materials, the time delay required could be of the order of half a minute or more whereas in small ferrous components, often the time delay is a matter of a few seconds only. The pressure level is affected by the work material as well as the complexity of the component and should, in general, be selected to the lowest possible level consistent with good internal structure of the squeeze casting. Essentially the same comments apply to the duration of pressure which should be long enough to complete the solidification under pressure but not so long that it could affect the tooling life adversely. The tooling temperature also depends on the work material and the part complexity but is normally in the range of about 400° to 700°F.

The principal advantages of the squeeze casting process can be listed as follows:

1. Ability to produce parts with complex profile and thin sections beyond the capability of conventional casting and forging techniques.

2. Substantial improvement in the material yield in comparison with sand casting because of the elimination of risers and gates.

3. Elimination of the labor associated with sand casting such as for molding, trimming of risers and gates, and cleaning of casting.

4. Substantial reduction in pressure requirements in comparison with conventional forging while at the same time increasing the degree of complexity that can be obtained on the parts.

5. Ability to utilize both cast and wrought compositions of work materials.

6. Substantially increased production rates in comparison with conventional casting techniques.

7. Possibility of substantial cost reduction in comparison with sand castings because of items 2 and 3 and in comparison with forgings because of the lower cost of the melt stock used for squeeze casting instead of the wrought materials used for forging.

8. Improvement in product quality such as the surface finish and mechanical properties in relation to sand castings. The generally harder as-squeeze cast material may also, in some cases, eliminate the need for further heat treatment.

2.2 Published Work

There are many references, generally in Russian publications, on squeeze casting. However, in this brief review we shall only refer to a few selected articles on ferrous squeeze casting.

Plyatskii(1) has discussed investigations on squeeze casting of cast irons. These are typically conducted at temperatures of 2300° and 2350°F using gray cast iron dies. The applied pressures for squeeze casting cast irons are quite low, being only of the order of 300 psi. Even such low pressures give a substantial improvement in product quality in terms of bend strength and tensile strength. The process is used in large-batch production of seats and valve bulk covers for gas engine compressors.

Plyatskii[1] has also considered squeeze casting of different items of steels weighing up to 44 lb. The die material was usually a carbon steel of the 1020 type and capable of die life up to 2000 or 3000 parts depending on the product and the precision required. The items he has mentioned are drill bits, collars, and gear blanks. He has also considered a special die design for production of components such as turbine blades. Essentially, the design consists of transferring the molten metal by means of a punch from a pouring well to the die cavity proper. Then, final forming and consolidation are conducted at a temperature where the metal is close to a plastic state. The advantage of such a die design is a relatively superior surface finish and freedom from any tearing.

According to the work reviewed by Bidulya,[2] the pressure should be applied at the moment of zero fluidity, which can be interpreted as the stage when continuous solid-phase skeletons are formed in a two-phase alloy. The zero fluidity temperature of steel is approximately midway between the liquidus and the solidus. At this moment, the punch can work the material with the least pressure and obtain a sound and homogeneous macrostructure. If pressure is applied earlier, the crust formed on the surface of the metal is ruptured and the molten metal inside flows over the ruptured crust forming defects. Bidulya also mentioned a temperature of pouring of about 90°F above the liquidus and refers to squeeze castings weighing up to 220 lb. He also states that after suitable heat treatment the strength, ductility, and toughness of squeeze castings were 10 to 15% higher than for the rolled steel and 20 to 30% higher than cast steel when similar compositions are considered. The yield of steel in squeeze casting can reach 90 to 95%, which is far in excess of other techniques such as forging, welding, or casting.

Bobrov et al.[3] have stressed the importance of accurately metering the melt volume. In their work the molten metal was displaced by lowering a float of known volume into the furnace causing it to overflow. The melt temperature was maintained 125 to 245°F above the liquidus, and the forming pressure was 12,800 psi. The holding time in the die was 5 to 15 sec before applying pressure and 8 to 20 sec under pressure. Experimental castings weighing 8.2 lb were made in steels of grades 1030, 420 stainless steel, and 321 stainless steel.

Bidulya and Zlodeev[13] have discussed squeeze casting of 1045 steel to make a hub weighing 115 lb and a hydraulic

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(13) P. N. Bidulya and V. N. Zlodeev, "Squeezed Steel Casting," Russian Castings Production, No. 4, April 1967, pp. 195-197.

press nut weighing 83.5 lb. They have also made references to some smaller test castings and have offered some general comments about the process.

Ryzhikov et al.[14] have described squeeze casting of 11.0 to 26.4 lb inserts in a tool steel to be used in forging dies. The melt preheat temperature was 120°F above liquidus, and the die preheat temperature was 390°F. For a 15.4 lb component with 2.16 in. thick walls, the solidification time under pressure was 20 to 25 sec.

Zubov and Began[15] used a die system which is comparable to that used for transfer molding of plastics. They squeeze-cast type 321 steel flanges of 7.5 lb weight and 1045 steel spur gears of 7.0 lb in weight. With their die system, the molten metal was poured into a receiving chamber below the die cavity. When the top die moved down, it pushed the lower die down against some springs, thus forcing the liquid metal from the receiving chamber into the die cavity. The quality of the product was found to be much better, and it was free of any laps and folds.

In making the flange in this fashion, the forming pressure was 13,100 psi and the duration of pressure was 18 sec. The temperature of the molten metal was 2910°F; the working temperature of the dies was 390°F. A cylinder oil was used as the lubricant, and the bottom of the receiving chamber was coated with an 0.012 to 0.020 in. layer of ordinary fire clay chill mold dressing.

As mentioned above, data on the preheat temperature of the dies are recorded by several different investigators. However, actual measurements of the surface temperature of the dies during squeeze casting ferrous parts are somewhat rare. This type of work has been conducted by Deordiev et al.[16] and to a limited extent by Cherniy and Zubov.[17]

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(14) A. A. Ryzhikov, L. D. Sorokin, V. N. Zhuravlev, and B. A. Naumchev, "Liquid Stamping of Steel 5KhNT," Russian Castings Production, No. 1, January 1970, pp. 20-21.

(15) L. A. Zubov and L. I. Began, "Stamping Components from Liquid Steel with Pressure-Filling of the Die," Russian Castings Production, April 1965, pp. 166-167.

(16) N. T. Deordiev et al., "Temperaturniy Rezhim Shtampovogo Instrumenta pri Zhidkoy Shtampovke" (Temperature Cycle of Dies During Liquid Metal Forging), Kuznechno-Shtampovochnoe Proizvodstvo, No. 9, 1965, p. 11.

(17) Yu. F. Cherniy and L. A. Zubov, "Shtampovka Detaley iz Zhidkogo Stali" (Liquid Metal Forging of Ferrous Parts), Kuznechno-Shtampovochnoe Proizvodstvo, No. 1, 1965, p. 21.

The conclusions reached were that the die surface temperature increased as a function of superheat of the melt, initial die temperature, pressure, and mass of molten metal. Maximum surface temperatures for steel squeeze castings ranged from approximately 1500° to 1900°F. The zone of maximum heating only extended 0.080-0.100 in. below the surface.

The die surface temperature is also influenced by the mold coating,[18-20] and therefore the coating should have good heat insulating property. The mold coating acts as a separating agent and reduces any tendency of welding between the work material and the dies. A good mold material should not react with the work material and should not generate any gas. The coating should be easy to apply and should have a good binder so that it is not washed into the casting when the molten metal is poured into the die or mold. As can be expected, the mold coatings have refractory materials as major components. Such coatings are used extensively in ingot molds and over chills, and the experience would be useful in selecting a coating in squeeze casting also.

Bidulya and Smirnova[21] contend that pressures of 10,000 psi or less will do for steel squeeze casting, and even lower pressures are adequate for cast iron squeeze casting. They claim die lives of 1250-2500 parts, which weighed 44 lb, using 1020 steel as a die material.

In a study of die life for steel squeeze casting, Ashtakov et al.[22] used a variety of different die materials

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(18) M. A. Baranovskiy and Ye. I. Verbitskiy, Shtampovka Zhidkikh Metallov (Liquid Metal Forging of Squeeze Casting), Gosudar. Izd-vo BSSR, Minsk, 1963.

(19) L. M. Soskin and N. S. Tokarskiy, Shtampovka Detaley iz Zhidkogo Metalla (Liquid Metal Forging or Squeeze Casting of Parts), Lenizdat, Leningrad, 1957.

(20) L. A. Malinovskiy, Shtampovka Zhidkikh Metalla (Liquid Metal Forging or Squeeze Casting), Luganskoe Oblastnoe Izdatel'stvo, Lugansk, 1959.

(21) P. N. Bidulya and K. N. Smirnova, "Osobennosti Protsessa Pressovaniya Zhidkogo Stali pod Bol'shim Davleniem" (Characteristics of the Process of Extruding Molten Steel at a High Pressure), Izvestiya Vysshikh Uchebnykh Zavedeniya, Chernaya Metallurgiya, No. 9, 1960, p. 43.

(22) A. F. Ashtokov et al., "Stoyukost' Shtampovogo Instrumenta pri Shtampovke Stali v Protsesse Kristallizatsii" (Die Life of a Punch Tool for the Liquid Metal Forging of Steel), Akad. Nauk SSSR Conference, 1967.

for the squeeze casting of a steel tractor component. The chief problem with type 1020 steel as a die material was its deformation and the consequent loss of punch tolerances. They claim that 3Kh2V8 (H21, nearest U.S. equivalent) heat treated to 39-40 R_C, was the best punch material (die life over 600 parts), with the failure mechanism being one of heat checking.

3. PART GEOMETRY AND TOOLING

This section describes the part geometry, target as a squeeze casting, and design and fabrication of the tooling for the receiver base and the barrel support. Since it was desired to find out the very limits of the capabilities of the process, the part geometry was selected as close to the finish-machined component as conceivable with the likelihood that many of the surfaces could be made net. As for the die material, common die steels were chosen for practically all the tooling except for a few small components that were deemed susceptible to damage and were, therefore, to be made from more expensive die materials. But in view of the small sizes of such components, the overall die costs were still likely to be substantially less than corresponding forging dies.

3.1 Receiver Base

3.1.1 Part Geometry and Current Method of Production

The finish-machined drawing for the receiver base, Part No. 7793063, per specification drawing by USAWECOM, Revision S, dated 26 July 1972, is reproduced in Fig. 2. The component is made of steel, the specification for which is described in Federal Specification QQ-S-681:Class 140-115. The composition of steel required to meet this specification is similar to AISI 8630 steel. In normalized, quenched, and tempered condition the properties required are 140,000 psi tensile strength, 115,000 psi yield stress, 10% elongation, and 25% reduction in area.

The receiver base is a part relatively simple in overall geometry but, as can be judged from Figs. 2 and 3, it is long and has thin sections. The finish-machined part which weighs only 6.2 lb is currently made from a sand casting (also shown in Fig. 3) which weighs 47 lb with risers and gates and 21.5 lb after trimming. Thus, it requires handling of a far greater quantity of melt than required for the finished component, and it must also be machined extensively. Both of these factors contribute significantly to its cost. The total machining time is approximately 8 hr per part. The item is required in quantities of about 100 to 150 per month or approximately 2000 per year. The plan area of the machined receiver base is slightly over 40 sq in., and its length is approximately 17 in. The part is characterized by a long, semicylindrical portion with walls as thin as 1/8 in.

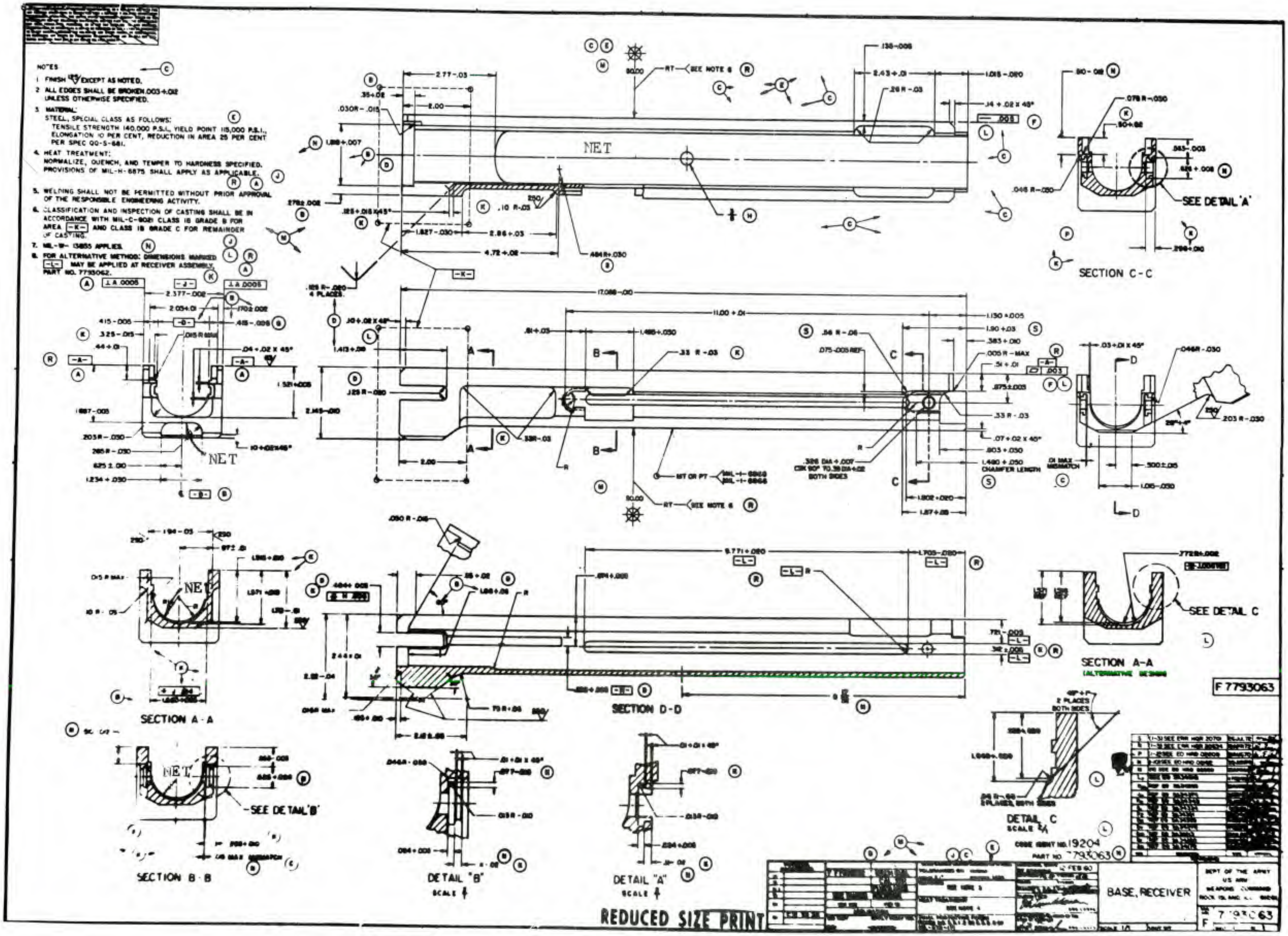

Figure 2 Machining Drawing of the Receiver Base.
(Target geometry of squeeze casting included surfaces marked NET which were to be squeeze cast to finished dimensions.)

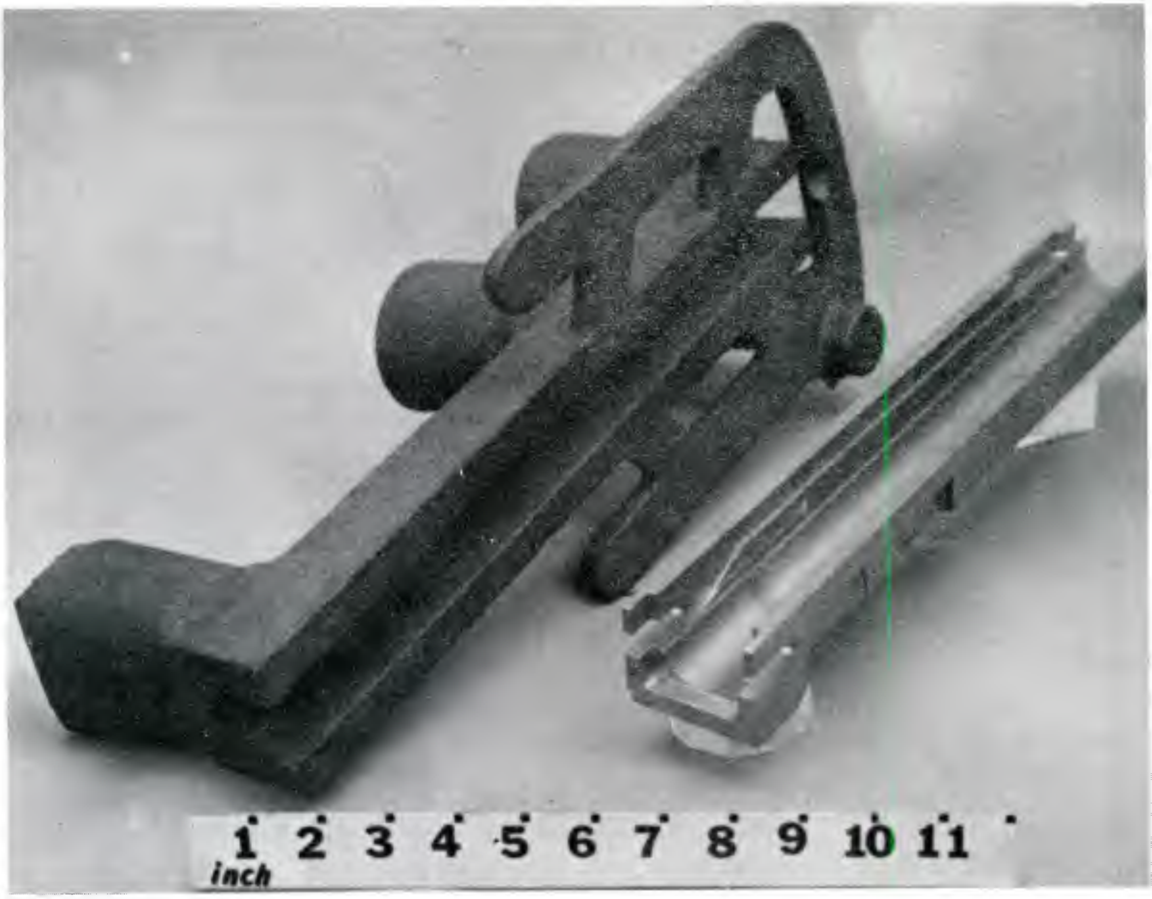

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Figure 3

Receiver Base Component Weighing Approximately 6.2 lb, Machined from an Untrimmed Sand Casting Weighing Approximately 47 lb.

3.1.2 Target as a Squeeze Casting

The long length and thin sections of the receiver base make it a very difficult part to squeeze cast. But, as mentioned earlier, since it was desired to judge the very limits of the capabilities of the process, initial geometry was selected to represent the most optimistic squeeze casting configuration. Then it was planned to modify, if necessary, the geometry on the basis of the initial squeeze casting tests. With this approach, it would be possible to make the squeeze castings as close to the finish-machined components as practical from the point of view of eventual large quantity production.

The target geometry of the receiver base squeeze casting is shown in Fig. 4. Attempt was made to squeeze cast the inside of the trough net, with no machining allowance. However, in other areas, a machining allowance of 0.06 in. was added. To enable usage of conventional machining techniques and thereby eliminate electrical discharge machining, the internal radii of the die cavity were kept large. This required the addition of extra material to surface B. Also, the grooves and detailed slots have been omitted from surfaces A and C because they would effectively create trapped regions which could prevent removal of the squeeze casting from the punch and bottom die.

3.1.3 Design and Operation of the Die

The design and fabrication of the squeeze casting dies required careful attention to the effect of component geometry on the various die components, and the various processing steps starting from the transfer of melt to removal of the completed squeeze casting from the die. A number of variations of the die design were considered, and the final design selected is shown in Fig. 5.

The punch and the bottom die for the receiver base were mounted in a standard two-post die set which is supported by mild steel rails as shown in Fig. 5. The lower die is essentially made from a single large block (with the exception mentioned in Section 3.3.1), whereas the punch is made from two pieces. The periphery of the punch support has only a small clearance of 0.004 in. per side with respect to the die cavity in the lower die. After the molten metal is transferred into the lower die and the dies are closed, the punch essentially seals the semisolid work material into the die cavity and the pressure can be applied and maintained in the material. The support rails provide clearance for the ejection system which consists of two ejection pins pushed by a

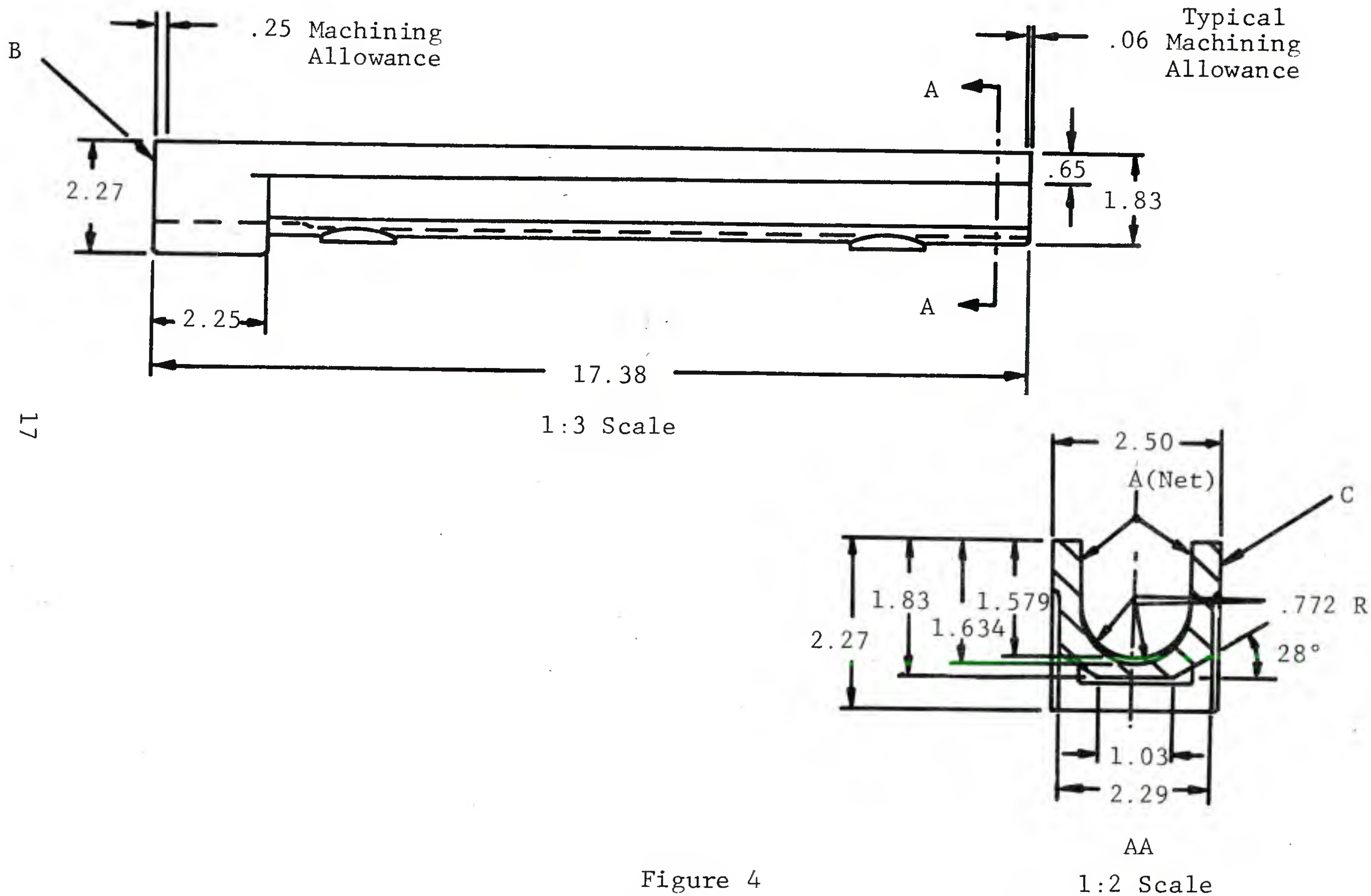

Figure 4

Target Geometry for Initial Squeeze Casting Tests for Receiver Base
(All dimensions in inches)

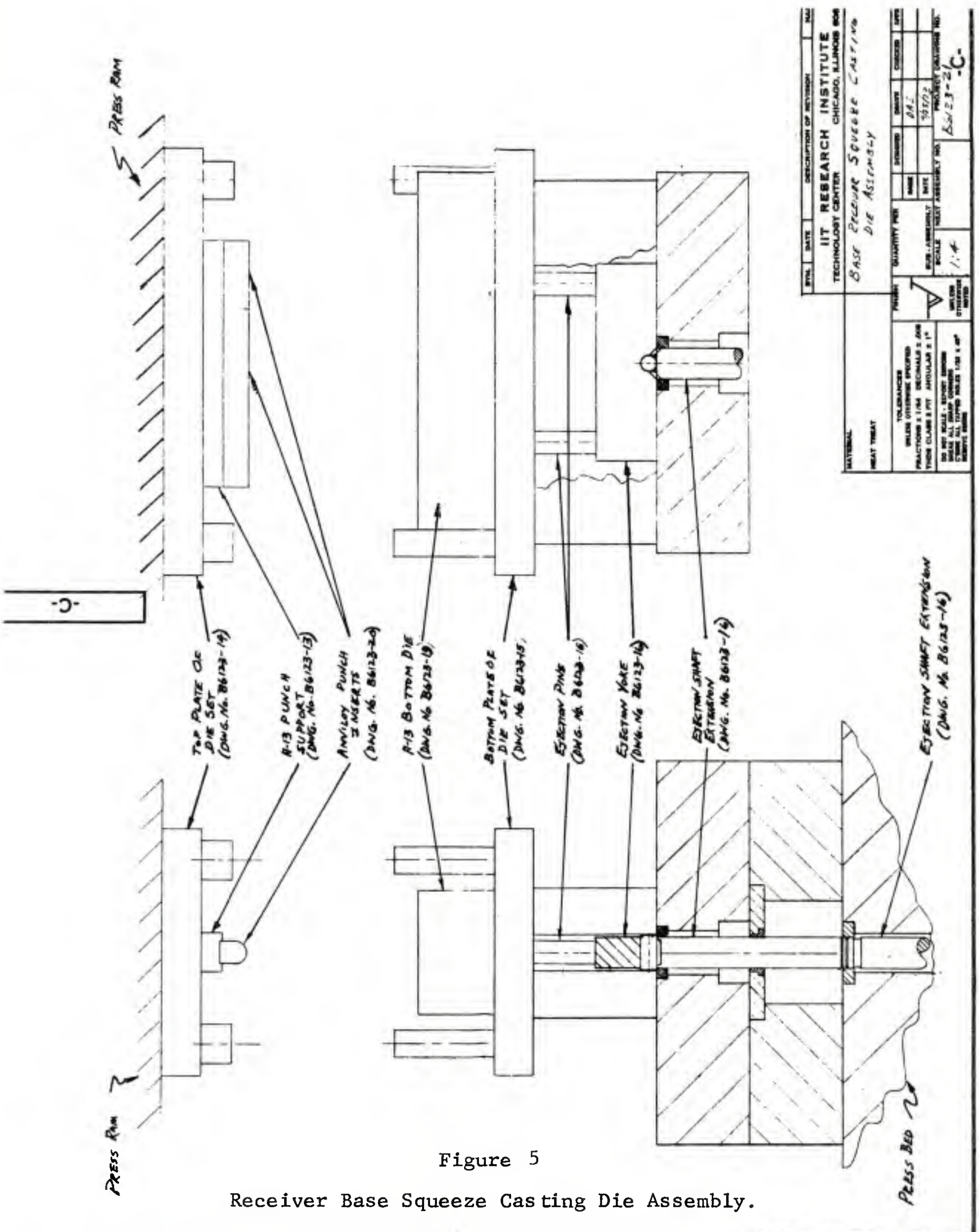

Figure 5

Receiver Base Squeeze Casting Die Assembly.

common yoke. A central ejection shaft applies the ejection force from a hydraulic cylinder to the yoke.

3.2 Barrel Support

3.2.1 Part Geometry and Current Method of Production

The finish-machined geometry of the barrel support is shown in Drawing Part No. 7793071, per specification drawing by USAWECOM, Revision K, dated 22 November 1967 and reproduced here as Fig. 6. The material for the component is steel per Federal Specification QQ-S-681: Class 150-125. The desired properties of 150,000 ultimate strength and 125,000 psi yield stress are currently obtained by a composition similar for 8630 steel. The heat treatment once again consists of normalizing, austenitizing, oil quenching, and tempering.

The barrel support (Figs. 6 and 7) is a part of much greater complexity than the receiver base. It has an overall length of about 14 in. and is essentially a cylindrical thin-walled tube with an open channel on one end. The wall thickness of the tube portion is only 1/8 in. in the machined condition, and its outside diameter is approximately 3 in. As a sand casting, Fig. 7, the barrel support weighs approximately 80 lb and 21.5 lb before and after trimming, respectively, and only about 7.4 lb in the machined condition. The extensive machining required on the part takes approximately 6 hr per piece. Once again, approximately 2000 parts per year are utilized.

3.2.2 Target as a Squeeze Casting

As in the case of the receiver base, the target geometry for initial squeeze casting trials for the barrel support was selected to test the very limits of the process capability. Thus the geometry shown in Fig. 8 represents the most optimistic geometry that could be conceived at the start of the program. It was planned to modify it subsequently on the basis of the initial squeeze casting trials when such modifications become necessary.

The basic differences in the geometry of this squeeze casting and the machined part are as follows: The pivot bosses (C, in Fig. 8) have been extended to the end of the part to facilitate ejection from the die. The grooves and detailed slots have been omitted (D, Fig. 8), as it was felt that the section thickness would be too thin at this point to be produced properly. The inside diameter of the tube (E, Fig. 8) is tapered from the clevis downward at a 1/2° angle to facilitate stripping from the punch. The material

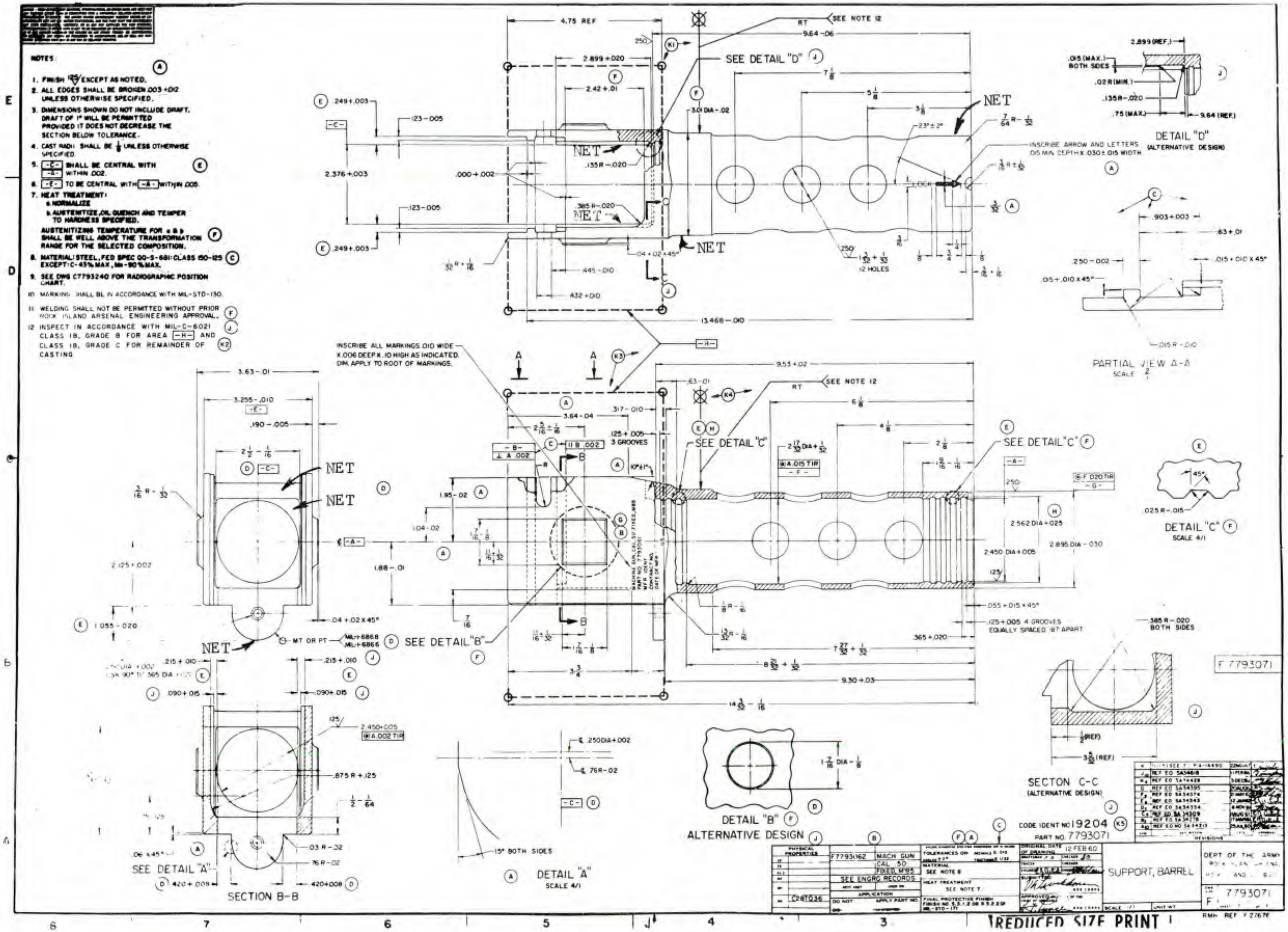

Figure 6 Machining Drawing of the Barrel Support.
(Target geometry of squeeze casting included surfaces marked NET which were to be squeeze cast to finished dimensions.)

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Figure 7

Barrel Support Component Weighing 7.4 lb Machined from an Untrimmed Sand Casting Weighing Approximately 80 lb.

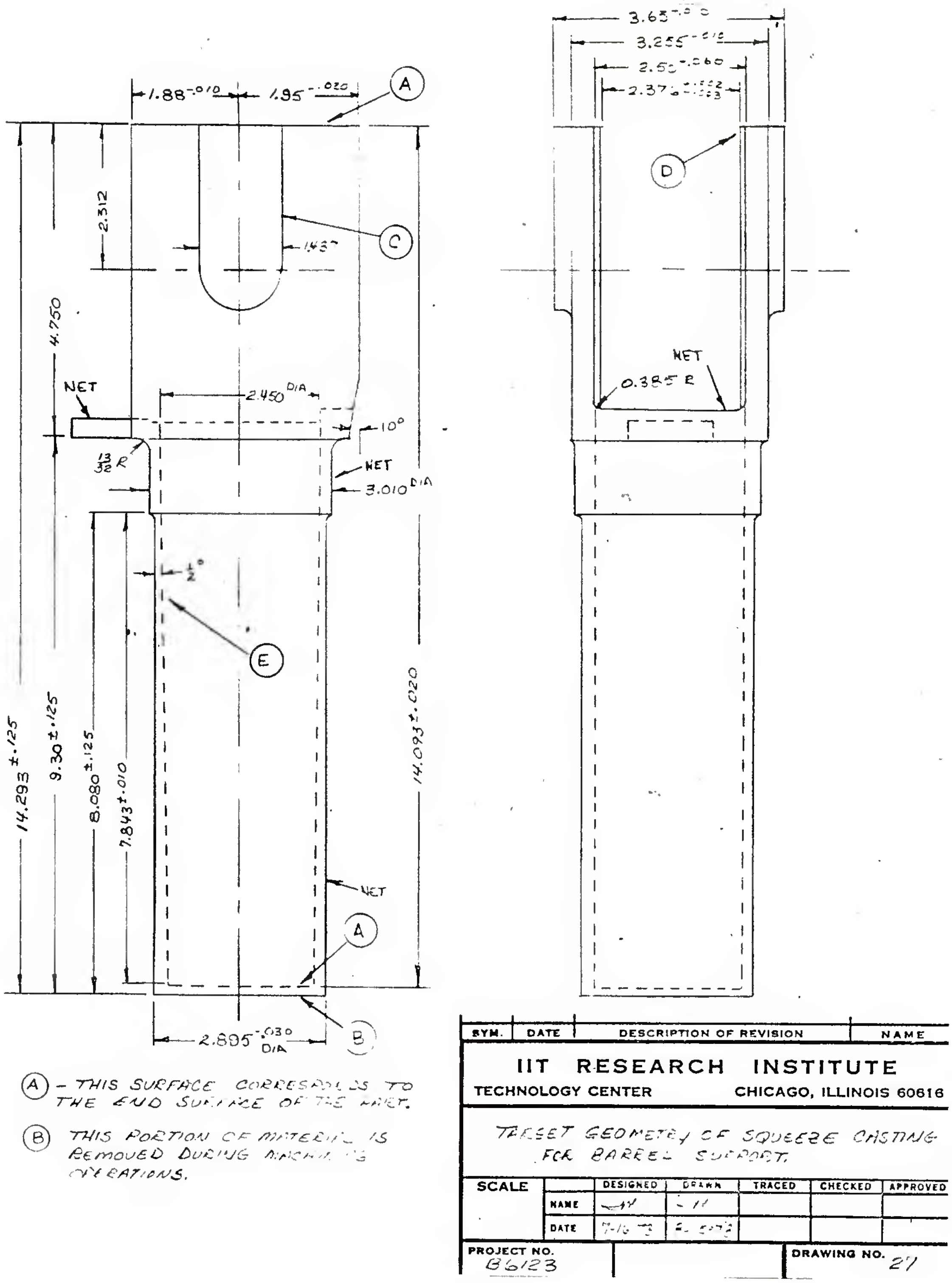


Figure 8

Target Geometry of Squeeze Casting for Barrel Support.

between A and B in the lower portion of the tube acts as a reservoir to make up for any small variation in the melt volume insuring the production of the (net) surfaces. This material is removed during a subsequent machining operation to produce the finished support.

3.2.3 Design and Operation of the Die

The die system was designed to provide somewhat of a double-acting motion. This system was needed to consistently produce the target (net) surfaces shown in Fig. 8. Since IITRI's past experience shows that the melt weights tend to vary approximately ±0.3 lb, it is obvious that the overall length of the barrel support would vary accordingly. With this in mind, the die was designed to keep the closed positions of the die body (E in Figs. 9 and 10) and the punch body (D in Figs. 9 and 10) constant to insure the definite relationship of the (net) surfaces produced by the two die components. The variation in the melt volume would then change the thickness of the base with no changes taking place between the relative positions of the punch and die body.

The operation of the barrel support die assembly is as follows:

Molten metal is introduced into the die cavity with the punch assembly in its uppermost position. The die then starts to close, and the following sequence of events begins. (Refer to Figs. 9 and 10.)

1. The punch pin (G) displaces the metal upwards as the die closes.

2. The punch connector plate (L) comes in contact with the stripper plate (C).

3. The whole die body (E) then is displaced downward guided by the four guide pins of the die set compressing the springs (I).

4. The downward movement ceases when the preset tonnage is reached and the die cavity completely filled.

5. After the proper hold time under load has been reached, the press is then reversed. The die body (E) then moves back along the guide pins until restrained by the bolts (J). At this point the upper punch continues to move

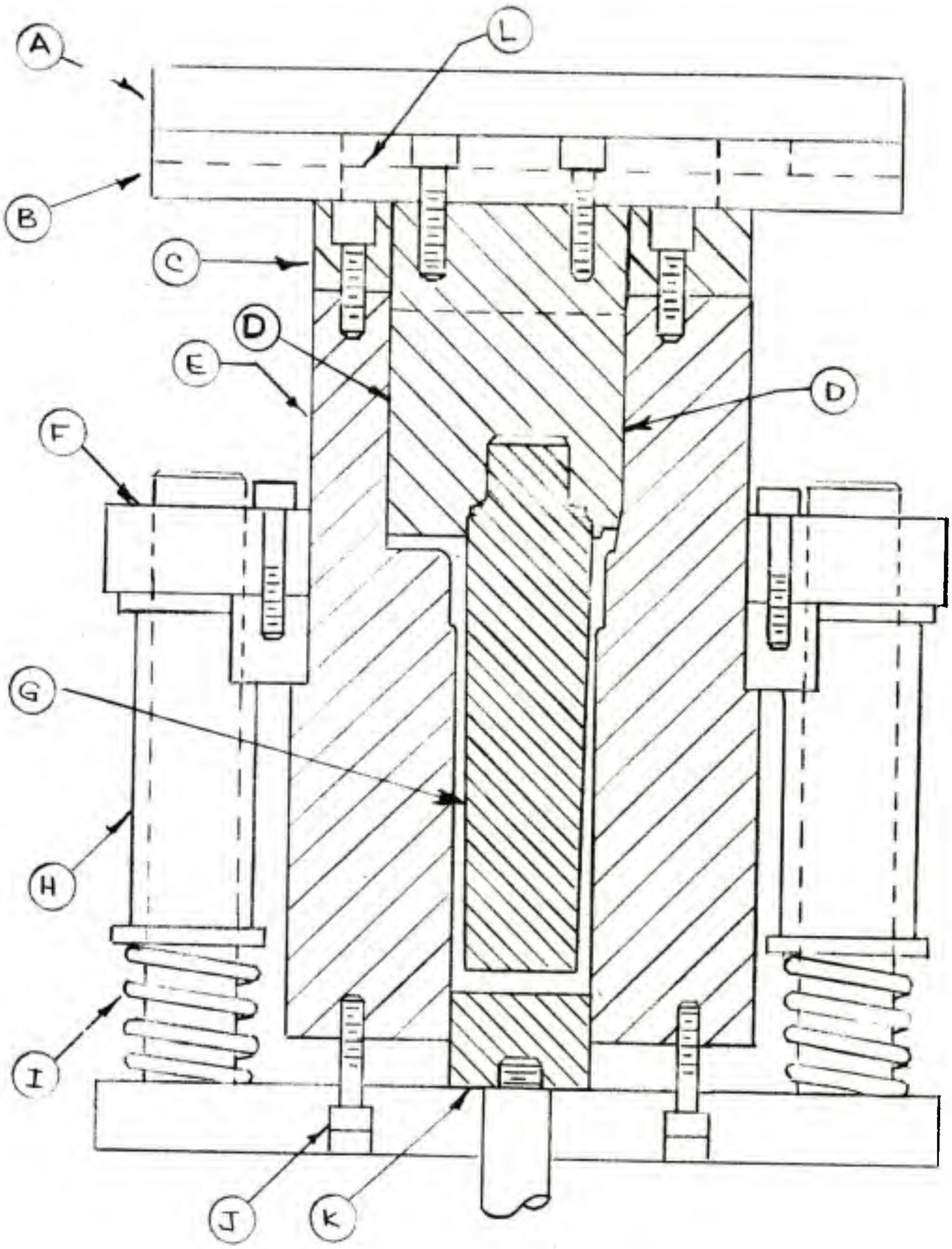
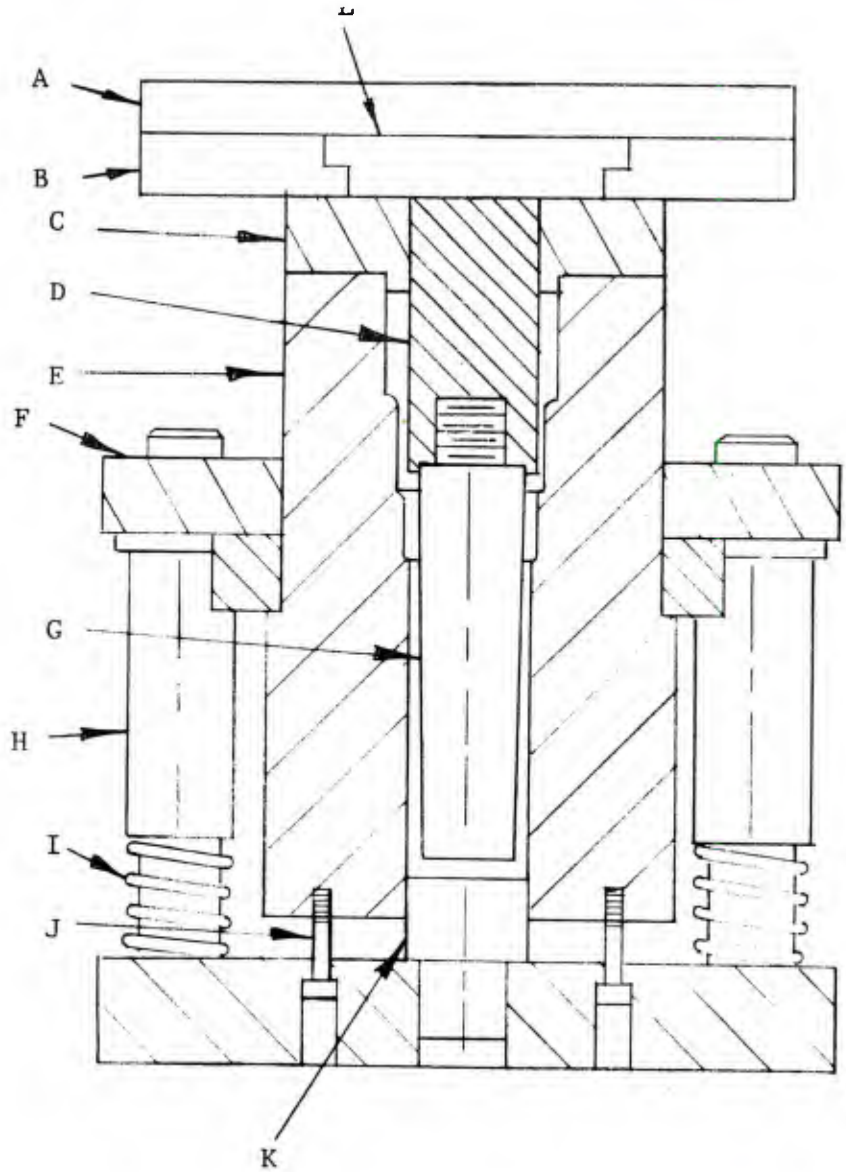


Figure 9.

Barrel Support Die Assembly, Sideview.

IITRI Dwg. No. B6123-28; Scale 1:4

For Legend, See Figure 10.



A - Punch Adapter Plate
H.R.S.

B - Punch Guide Plates
H.R.S.

C - Stripper Plate
H13, R_C 38-40

D - Punch Body
H13, R_C 38-40

E - Die Body
H13, R_C 38-40

F - 4 Post Die Set

G - Punch

H - Spacer Sleeve
H.R.S.

I - Spring - 1400 lb/in.

J - Restraining Bolts
4340 - heat treated

K - Ejection Pin
Anviloy 1150

L - Punch Connector Plate
H.R.S.

Figure 10

Barrel Support Die Assembly, Front View

upwards until free from the die body along its entire length. The barrel support remains in the die cavity restrained by the stripper plate (C). At this point the bolts holding the punch connector plate (L) are removed and the entire punch is moved laterally along the guide plates (B) to a point permitting free ejection of the barrel support.

6. The bolts holding the stripper plate (C) are then removed permitting the ejection of the barrel support. The springs (I) return the die body to its upper position.

7. The die is then reassembled for another run.

Note that the daylight restrictions of IITRI's 250-ton press necessitated the use of a movable upper punch. In a production situation, however, a press with adequate daylight would be used, eliminating this assembly and disassembly procedure.

3.3 Die Material*

3.3.1 Die Material Selection

A combination of H13 tool steel, Anviloy (1150), and mild steel is used to provide maximum die life at minimum cost. The properties of Anviloy 1150, which is a tungsten-base alloy developed primarily for die casting tools, is compared[23] with H13 tool steel in Table 1. Although its resistance to thermal fatigue and erosion should be beneficial for squeeze casting dies, its use was kept to a minimum because of its high cost and the limited size range available. The net surface on the receiver base squeeze casting (Fig. 4) was to be produced with punch components made of Anviloy 1150. It was hoped that the use of this material would minimize die erosion and therefore maintain the close tolerance necessary when squeeze casting a net surface. However, since Anviloy 1150 is only offered in a limited size range, it was necessary to make the punch insert from two pieces of the material. Likewise, Anviloy inserts were provided in the

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*This section pertains to decisions made at the start of the program. Subsequent modifications are discussed in Section 5.

Table 1

A COMPARISON OF PROPERTIES OF DIE MATERIALS[a]

Properties	Anviloy 1150	AISI 1045	H13	Inconel 718	Inconel 713C
Analysis, wt%	W 90	C 0.46	C 0.40	C 0.04	C 0.12
	Ni 4	Mn 0.75	Mn 0.30	Mn 0.20	Cr 12.5
	Fe 2	P 0.035	Si 1.00	Si 0.30	Ni Bal.
	Mo 4	max	Cr 5.00	Cr 18.6	Mo 4.2
		S 0.045	V 1.00	Ni Bal.	Cb 2.0
		max	Mo 1.35	Mo 3.1	Ti 0.8
		Fe Bal.	Fe Bal.	Cb 5.0	Al 6.1
				Fe 18.5	B 0.012
				Ti 0.9	Zr 0.10
				Al 0.4	
Density, lb/in.^{3}	0.6	0.283	0.28	0.296	0.286
Coefficient of Thermal Expansion x 10^6/°F					
68-752°F	2.52	7.5	6.8	7.85	7.20
80-1450°F	2.92	7.6	7.5	9.0	8.28
Thermal Conductivity					
Btu/ft^2/hr/°F/in.	750	360	198	78	138
cgs units	0.306	0.124	0.082	0.027	0.048
Typical Room-Temperature Mechanical Properties					
Hardness, R_C	34	(152)[b]	45	--	--
Ultimate tensile strength, ksi	140	70	233	208	123
Yield strength, 0.2% offset, ksi	125	34	192	172	107
Elongation, % in 2 in.	3.0	20	13.1	21	7.9
Modulus of elasticity, psi x 10^{-6}	49.0	30.1	30.5	29.0	29.9
Elevated Temperature UTS, ksi					
1000°F	113	42	142	185	125
1200°F	105	22	85	178	126
1500°F	75	8	21	94	115

[a]Compiled and estimated from references 23-25; [b]Brinell hardness.

(23) Mallory Metallurgical Co. (Technical Bulletin), "Anviloy 1150. Tool Material for Die Casting," Mallory Metallurgical Co., Division of P. R. Mallory & Co., Inc., Indianapolis, Indiana.

(24) C. J. Smithells, Metals Reference Book, Vols. I and II, Interscience Publishers, Inc., New York, 1955.

(25) High Temperature, High Strength Nickel Base Alloys (2nd ed.), The International Nickel Company, Inc., June, 1968.

bottom of the receiver base die to minimize die erosion from the incoming stream of molten metal during pouring.

The barrel support die, Figs. 9 and 10, offered several problems which precluded the use of Anviloy 1150 to produce the net surfaces. The main problem was, again, the size of the die components versus the limited size range of Anviloy available. However, the punch pin, G in Figs. 9 and 10, and the ejection pin, K in Figs. 9 and 10, were originally made from Anviloy 1150 as these would be the components that would be most susceptible to erosion and deformation due to overheating during the squeeze casting process. Later, other materials such as Inconel 718, Inconel 713C, and mild steel were also used as punch materials, as discussed in Sections 5.2 and 7.

3.3.2 Dimensional Considerations

The final dimensions of the die cavity depend on the thermal expansion of the tooling and squeeze casting, and on the machining allowance left on the squeeze casting. Since the tooling expands as it reaches squeeze casting temperatures and the receiver base shrinks during cooling after squeeze casting, the room-temperature die dimensions are a function of both the thermal expansion of the tool material and of an anticipated shrinkage factor for the squeeze casting. For example, with H13 die components, the die dimensions will increase 0.00475 in/in at an operating temperature of 700°F above room temperature. From past experience, it was assumed that the squeeze casting would typically shrink about 0.001 in/in upon cooling. For a room-temperature squeeze casting dimension of 10 in., this would require a die dimension of 10.010 in. at 700°F above room temperature. This die dimension, however, is 0.0475 in. larger than the corresponding room-temperature dimension because of thermal expansion. Therefore, the actual die size at room temperature is 9.963 in. Based on the 0.001 in/in shrinkage factor, the room-temperature H13 dimension is 0.037 in. smaller than the room-temperature squeeze casting dimension. However, the squeeze casting shrinkage factor was too conservative with the result that modifications were required to the receiver base die (see Section 5.1).

A similar approach can be applied to Anviloy components; but since the coefficient of thermal expansion is very small, the room-temperature Anviloy dimension is about 0.999 that of the room-temperature squeeze casting dimension.

It is desirable to minimize the punch to die cavity clearance to reduce the possibility of producing flash during squeeze casting. However, punch-to-die scuffing must also be avoided. When the punch and die are made of the same material, maintaining the proper clearance only requires minimizing the temperature difference between mating components during squeeze casting as in the barrel support punch and die. The receiver base squeeze casting die, however, uses both H13 and Anviloy which have widely differing coefficients of thermal expansion and coefficients of thermal conductivity. The approach used was to minimize the room-temperature clearance between components of the rapidly expanding but less conductive H13 material and the slowly expanding but highly conductive Anviloy because the die heating would increase the clearance. This approach permitted die assembly at room temperature, and also minimized die clearances at squeeze casting temperatures. Even though Anviloy may attain a temperature higher by as much as 500°F than the H13 components because of the high thermal conductivity exhibited by Anviloy, this approach should still lessen any chance of binding between components of the dissimilar materials since the Anviloy has a lower coefficient of thermal expansion.

Basically similar procedures apply to the barrel support die set. However, the plan dimensions of the barrel support as it is squeeze cast are quite small and the mating members are made from the same material. Consequently, the importance of the dimensional considerations is much less in this case.

4. EQUIPMENT AND PROCEDURAL DETAILS

4.1 Hydraulic Press

IITRI's 250-ton hydraulic press was utilized for the experimental work. The press has a bed area of 24 x 24 in. with 51 in. of daylight. It has a direct pump, variable-speed hydraulic drive with an 80 ipm maximum pressing speed. Mounted beneath the press is a hydraulic ejection cylinder connected to an accumulator. This cylinder is capable of exerting an ejection force of 23 tons maximum.

The 250-ton capacity of the press was adequate for squeeze casting both the receiver base and the barrel support, and the bed area of the press was sufficient for dies made according to the designs in Figs. 5, 9, and 10. However, several other limitations of the press made the experimental work considerably more difficult than was originally expected. The more severe of this was the low force available for retracting the ram, this force being only 10% of the load setting used for the squeeze casting operation. In conventional forging operations for which the press was originally designed, very little force is required to retract the ram. However, in squeeze casting of complex parts, the thin metal flash extruded between the mating parts of the top and lower die demands much greater force for separating the two die halves. As discussed in greater detail later, for the barrel support in particular, it was often impossible to retract the punch immediately after squeeze casting. This caused the squeeze casting to cool and shrink around the solid metallic punch causing severe cracking in many squeeze castings and on several occasions the die set had to be practically disassembled to remove the stuck casting prior to continuing with additional trials.

The daylight of 51 in. was inadequate for the barrel support with an overall length of 14 in. and this made it necessary to make the punch of the barrel support die set capable of retracting sideways to facilitate removal of the squeeze casting from the lower die as discussed earlier. Also, the low amount of space available below the press bed limited the length of the hydraulic ejection cylinder that could be used and, to a certain extent, also limited the available force capacity. In the receiver base die set, a yoke-type of dual ejection system was used and subsequently, as discussed in Section 5.1, auxiliary hydraulic cylinders had to be added for which the press did not have any room below the bed. Elaborate tooling design was, therefore, essential to accommodate the auxiliary cylinders.

The effect of these difficulties are discussed in greater detail in subsequent sections in terms of tooling design requirements and effect on squeeze casting component quality. However, they are enumerated here to emphasize the various factors that should be taken into account in ordering a new press for a production facility for squeeze casting operation. When using an existing press such as the case was for the subject program, this freedom does not exist but attempt has to be made to overcome the limitations through tooling design.

4.2 Melting and Melt Transfer Facilities

A 20 lb capacity induction melting furnace supplied by a 9600 cycle 40 kva generator was used for all the squeeze casting trials. The furnace consists of an induction coil mounted in an alumina and Transite frame which is fitted with trunnions. The metal is melted in an alumina liner which is fixed inside the coil using refractory plaster. The alumina liner is a closed bottom tube approximately 9 in. long with a 3 1/2 in. inside diameter.

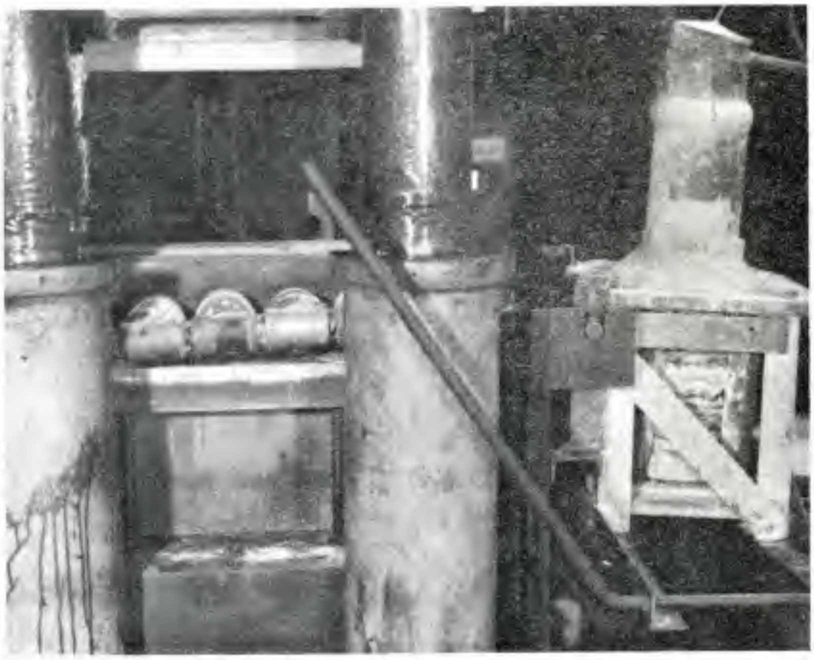
IITRI's experience in various squeeze casting projects had pointed out the need for good transfer techniques of molten metal from the furnace to the die. In fact, if this transfer can be achieved without any manual handling by means of a transfer ladle, the overall operation is easier and the quality of the squeeze casting is improved. For this purpose, the induction melting furnace was mounted directly on the frame of a 250-ton hydraulic press as shown in Fig. 11. This permits melting the metal right next to the press and adding the metal into the die merely by tilting the furnace on its hinged support. The length of the liner must be suitably adjusted according to a different die set so that the metal enters the die cavity without any spilling on the sides of the dies. The individual setup and techniques used for the barrel support and receiver base squeeze castings are described in Section 4.6.

4.3 Melting Technique, Composition Control, and Melt Transfer

To obtain the molten steel for squeeze casting, the furnace was typically charged with 8620 steel shot which was melted before the necessary additions of ferromolybdenum (39% Fe, 61% Mo), electrolytic manganese, and eutectic shot (Fe + 4.3% C). Aluminum was also added as a deoxidant. The melting of 12 to 17 lb of steel required typically 20 to 30 min. Oxidation of the melt was minimized during melting by keeping the furnace covered with argon gas fed through the furnace lid at a rate of approximately 20 cfm.

8630 steel shot was used for initial receiver base and barrel support squeeze casting experiments. However, this alloy is not commonly made so subsequent quantities of melt stock were of 8620 steel. Both the 8630 and 8620 steel shot were purchased from Cannon-Muskegon Corporation, Muskegon, Michigan. The composition of the supplied stock is given in Table 2. To meet the QQ-S-681 property specifications, additions of carbon and molybdenum were made to improve hardenability of the squeeze casting. The final quantity of carbon and molybdenum as well as manganese was made comparable to the composition presently used for the sand-cast version of the receiver base and barrel support components. The quantities of additions were decided on the basis of a few initial squeeze castings by analyzing their composition.

As described in Section 4.6, the molten steel was poured directly into the die cavity. In both dies, the incoming molten metal stream was intended to impinge against an Anviloy insert to minimize the possibility of eroding or welding the steel die components. The initial pouring technique for the



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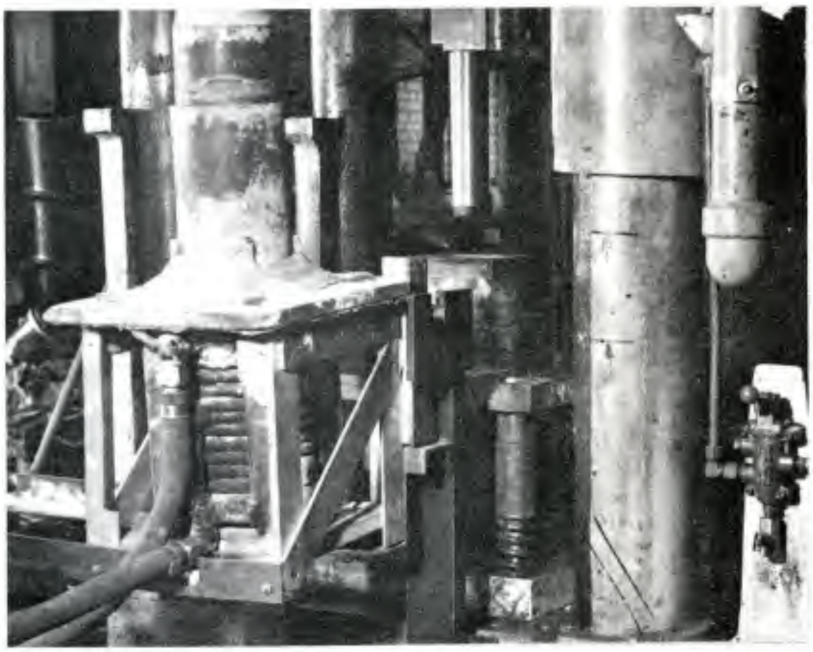
(a)



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(b)

Figure 11

Two Views of the Induction Melting Furnace Mounted Directly on the 250-Ton Hydraulic Press.

Table 2

COMPOSITIONS OF MELT STOCK

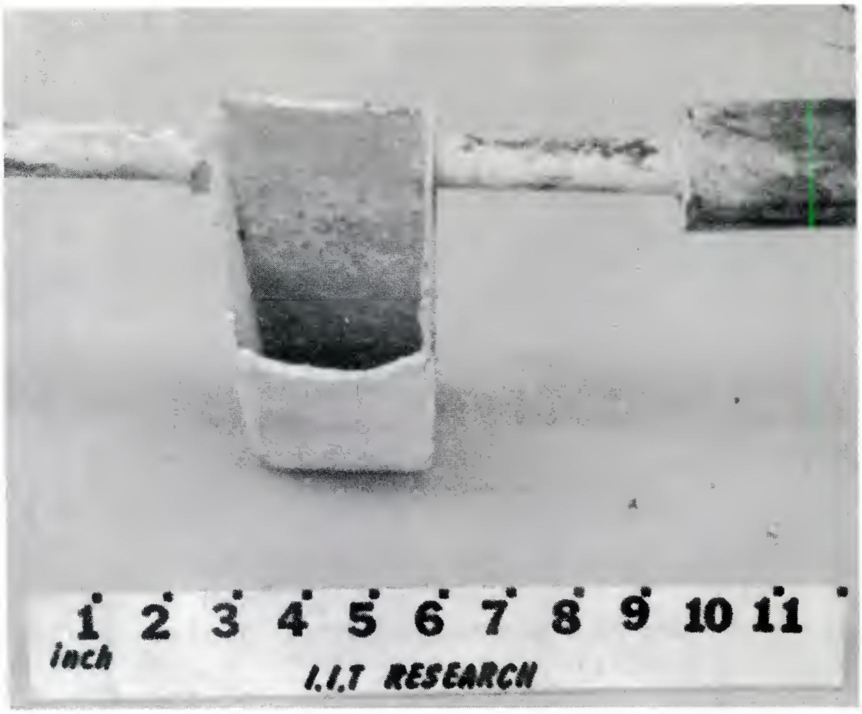
Identification	Composition, wt%							
	C	Mn	Si	P	S	Ni	Cr	Mo
8620, Heat No. S-R-282	.24	.65	.43	.012	.021	.51	.53	.20
8620, Heat No. S-R-285	.23	.73	.45	.013	.020	.56	.52	.22
8630, Heat No. AP-15	.32	.85	.60	<.03	.022	.51	.51	.20
8620, Heat No. S-R-291	.24	.76	.48	.013	.020	.51	.59	.20
Typical Sand Casting at RIA	.25	.75	.50	<.010	<.010	.50	.55	.55

receiver base die used a long furnace extension which could reach a centrally located Anviloy insert in the bottom die cavity. Pouring in this manner was satisfactory, but the long furnace extension required considerable daylight between the die halves. This increased the ram movement and also made furnace manipulation slightly slower. Elapsed time from the first molten metal leaving the furnace to application of pressure was typically 9 sec. Although this represents a very fast transfer and loading sequence, reducing this time would mean that the molten metal in the die would be hotter when contacted by the top die. This is desirable because the surface finish could be improved and shrinkage porosity reduced without increasing melt temperature or load. Therefore, the furnace extension was reduced to a length which slightly extended into the die cavity. Although the molten metal now washed against the tool steel die surfaces instead of on the Anviloy insert, the disadvantage of shorter die life was offset by the improved melt transfer with the elapsed time from start of pour to application of load now only 6 sec.

Pouring molten metal into the barrel support die was much more difficult because the opening in the bottom die is very small and the metal must ideally collect in the bottom of the die without washing against the long vertical die walls. Contact between the molten metal and the die walls would create two problems. First, a thin layer of steel could solidify on the die wall where contact was made between the incoming stream of metal and the die. This skull would then have to be remelted, but complete remelting is difficult and the skull would then become a source of defects.

A second and more serious side effect of contact between the incoming stream of metal and the steel die walls is the possibility of welding. Although slow, careful pouring and a generous application of mold wash would minimize the problems of skull formation and/or welding, a better solution is required since slow pouring allows more cooling of the melt and mold wash buildup affects the squeeze casting dimensions.

The best pouring method developed with the barrel support die consisted of the sheet metal pouring guide shown in Fig. 12. This guide is fabricated from mild steel and coated with mold wash. It is preheated prior to pouring by aligning it adjacent to the die heating burners. Just prior to pouring, it is placed in the opening of the bottom die. The molten metal is then quickly poured through it. The guide is then removed and the dies are closed. The guide acts as a funnel by directing the stream of molten steel down through the die opening. Also, the portion of the guide projecting above the die opening acts as a deflector for the incoming



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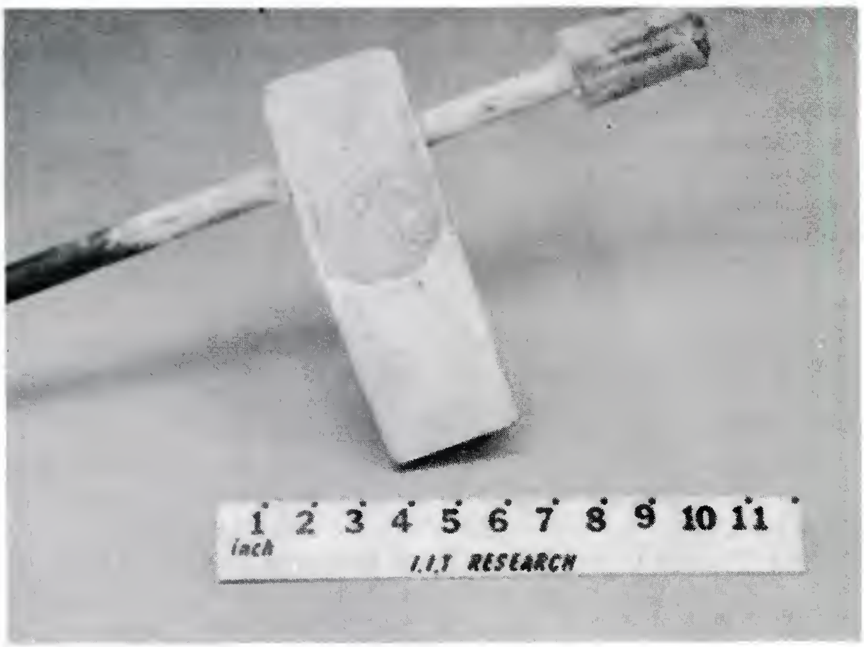
(a)



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(b)

Figure 12

Two Views of the Sheet Metal Pouring Guide
Used for Pouring Molten Steel into the
Barrel Support Die.

stream of molten steel. The net effect is a very fast transfer time and no welding or skull formation. The time from start of pouring to application of load was 9 sec.

4.4 Die Heating

The temperature of the squeeze casting die is important because a preheated die will delay solidification of the molten metal until pressure can be applied. However, the maximum preheat temperature must be safely below the tempering temperature of the H13 die material, whereas a minimum temperature of 600°F is required for reasonable die toughness and to minimize thermal stresses.

A specially designed manifold for gas heating each die assembly was used. The receiver base die had as many as eleven gas burners and the barrel support manifold had fifteen burners. For a temperature of 600°F, a 3 hr or less preheating time was required at the start of a casting series depending on die insulation, the number of burners, and the gas flow rate. To obtain uniform heat on the punch and the die, during heating the dies were held in closed position. The only exception was in the case of the receiver base die set with Anviloy punch where it was desired to allow for the differential thermal coefficient of expansion of the Anviloy and die steel materials and, therefore, the dies were kept in open position during heating and were heated by separate burners. In production, because of quick succession of the squeeze castings, the die temperature can be maintained without heating once the series is started. In fact, there may be need for cooling the dies to maintain them in the desired temperature range.

4.5 Die Pretreatment and Mold Wash

Freshly machined die steel surfaces must be conditioned before squeeze casting to minimize the possibility of the squeeze casting welding to the die surface. This conditioning consists of heating the die steel component to approximately 1000°F to give the surface a protective oxide layer. With use, the die steel becomes increasingly oxidized and the resistance to welding increases. However, an additional coating of mold wash is generally required to further protect the dies against welding.

Anviloy has a high resistance to oxidation and shows little tendency to weld. Squeeze casting die components made of Anviloy are used, therefore, with no pre-squeeze casting oxidizing treatment, but with a coating of mold wash.

Superalloys, such as Inconel 718, have a relatively low melt temperature so that the possibility of welding to a steel squeeze casting is great. Therefore, before starting a squeeze casting series, the Inconel 718 punch was coated with Markal CRT-22, which is manufactured by Markal Company, Chicago, Illinois. Markal CRT-22 melts in the range of 1400°F forming a glass-like coating. Additional protection was provided by adding small amounts of mold wash to the CRT-22 coating. The punch was coated at room temperature and then heated in an electric furnace to 1650°F to melt the coating. After cooling, the punch was put back in the die assembly, heated to squeeze casting temperature, and then given an additional coating of mold wash to further protect against welding.

Nalco 839-P, an alumina-base material, made by Nalco Chemical Company, Chicago, Illinois, was mixed with water and used as a mold wash for all of the initial squeeze casting experiments. The technique of coating the die surfaces with Nalco 839-P consists of spraying the mold wash on the die surface which has been preheated to approximately 600°F (between successive squeeze castings, the temperature may reach as high as 900°F). A Binks type 160-B oil spray gun was used for applying the mold wash coating. Depending on the die temperature and spray technique, layers as thick as 0.03 in. could be applied. However, thick coatings reduce the dimensional precision of the squeeze casting and also are more prone to spalling during pouring so the typical layer thickness was in the range of 0.005 to 0.015 in. A sheet metal spray guard limited the mold wash application to that portion of the die which actually comes in contact with the molten metal. Since this leaves the sliding areas free of mold wash buildup, scuffing between the die halves is minimized.

The evaluation of squeeze castings discussed in Sections 6 and 7 showed that the surface finish of the squeeze castings was affected adversely by the roughness and unevenness of the ceramic mold wash. In the course of the work, it was found out that instead of the ceramic mold wash, carbon soot buildup on all the die cavity surfaces by usage of an oxy-acetylene torch with inadequate supply of oxygen acted as a very effective mold wash. This technique was used in later series of squeeze castings for both the receiver base and the barrel support and the consequent improvement in the surface finish is described in Sections 6 and 7.

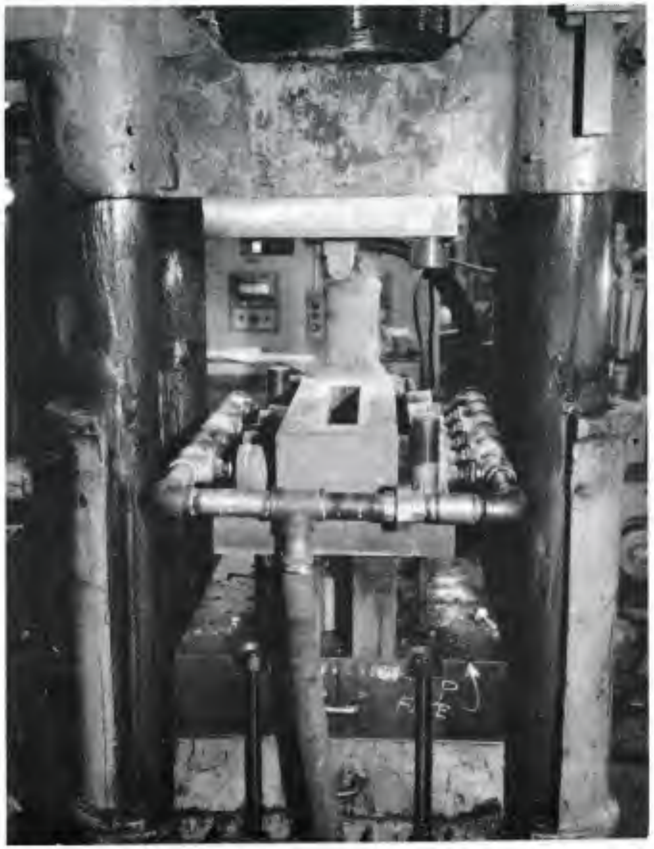
4.6 Experimental Procedure

The experimental sequence for both the receiver base and the barrel support started with loading the required quantity of melt stock in the induction furnace and melting it, which took about 20 to 30 min. Then, the necessary additions of carbon, manganese, and molybdenum were made and, just prior to pouring, a deoxidizing addition of aluminum was also made. Then, the temperature was checked with an immersion type platinum-rhodium thermocouple protected by a fused silicon tube. At this time the press was opened and the ram positioned so as to minimize the stroke for squeeze casting but still permit pouring. Power to the furnace was turned off, and the metal was poured into the die. The dies were then closed and the pressure was maintained for the desired interval. The dies were then opened and the squeeze casting was ejected. After ejection, die preparations including retraction of ejection pin and application of mold wash are executed while the melting furnace is recharged for the next squeeze casting sequence.

4.6.1 Receiver Base

Figure 13 shows the receiver base assembly mounted in the press and the position of the melting furnace during melting (Fig. 13a) and during melt transfer (Fig. 13b). It can be readily noted that the melt transfer occurs so that the movement of the molten metal stream is along the length of the die cavity. This minimizes the obstruction to the melt stream by the die wall and helps improve the quality of the squeeze casting. Typically, the time required to tilt the furnace and transfer the molten metal into the die, close the dies and apply load was about 6 sec. In the majority of the experiments, the dies were closed at 600 ipm and remained closed for the desired duration. The load was then relaxed, but the dies remained closed. This permitted the squeeze casting to cool before withdrawing the punch and minimized the possibility of bending the squeeze casting. After withdrawing the punch, the squeeze casting was permitted to cool until it reached approximately 1200°F. Then the squeeze casting, which normally remained in the lower die, was pushed out with the help of the ejection system while the ram was bearing on the casting with spacer blocks to minimize bending or caulking of the casting during ejection. The ejection cylinder was then retracted and the pins returned to their original down position.

For starting the next cycle, mold wash was spread onto the die cavity with a sheet metal spray guard limiting the mold wash application to those portions of the die which actually come in contact with the molten metal. This was



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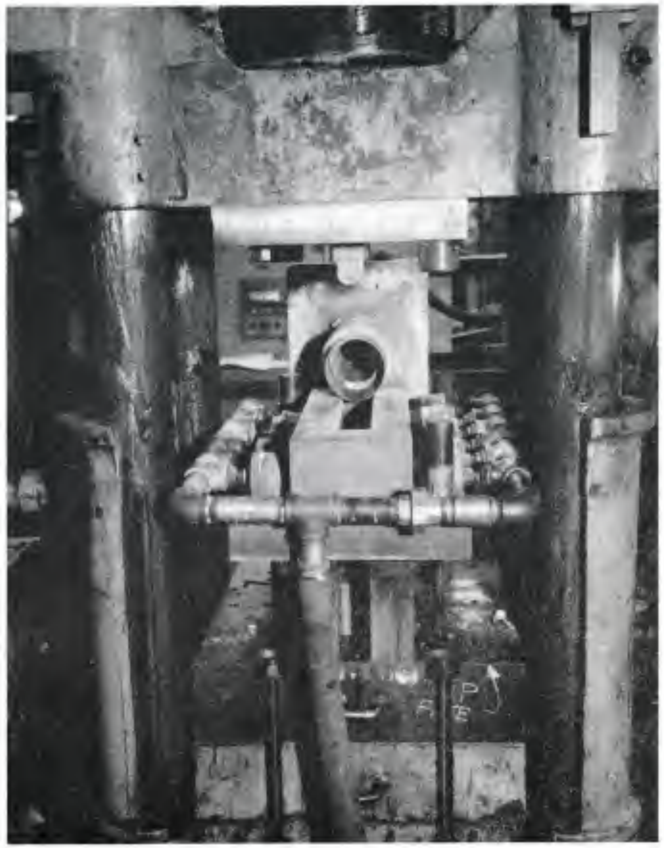
(a)



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(b)

Figure 13

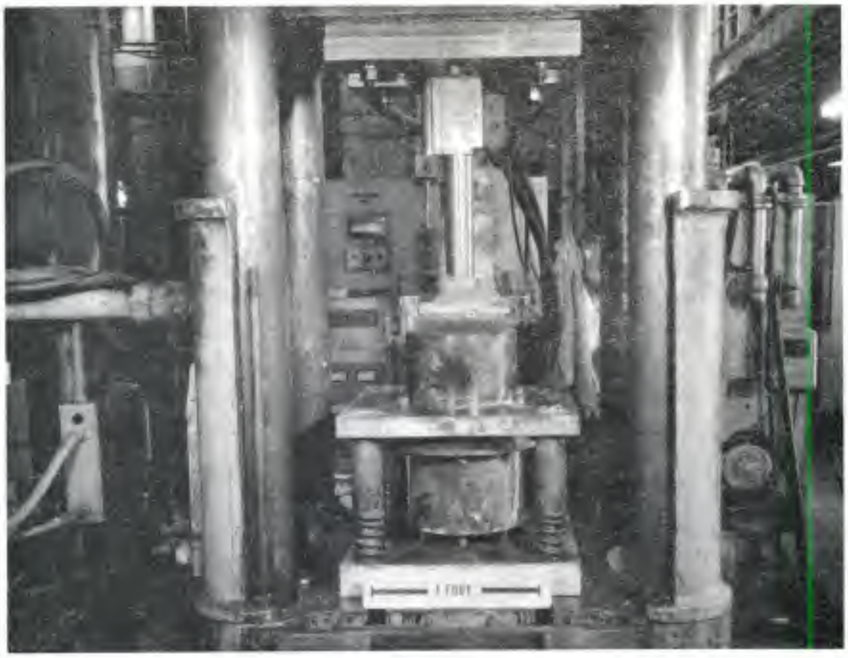
Two Views of Receiver Base Die Set Mounted in Press, Looking Along the Length of the Die. (a) Melting furnace in vertical position, (b) melting furnace in pouring position.

important during the initial series when a ceramic mold wash was used. In later series when carbon soot was the mold wash, this was unnecessary since the carbon soot also had some lubricating quality, and its presence at the sliding areas of the die component was acceptable. The die was then closed to reheat the punch while the next charge was being melted.

4.6.2 Barrel Support

Two views of the barrel support die set mounted in the press are shown in Fig. 14. For transferring the molten metal the furnace was tilted and the molten metal was transferred into the lower die using the pouring guide shown in Fig. 12 to guide it straight down without touching the vertical sides of the die cavity. From the moment tilting of the furnace was begun, the molten metal was transferred into the die, the dies closed, and to reach the point where the load was built up took about 9 sec. The dies were closed at about 600 ipm, and the load was maintained for the desired duration. Then the ram was immediately retracted to prevent the casting from shrinking onto the punch and cracking. (As mentioned in Section 4.1, occasionally the press force capacity was inadequate to retract the ram.) Then the stripper plate retaining screws were removed to permit ejection of the squeeze casting. The screws retaining the punch connector plate were removed and the punch was pushed to one side to provide clearance for removing the squeeze casting. The ejection system was then activated, pushing the squeeze casting partially out of the die. Then the casting could be lifted out of the dies with a pair of tongs.

For the start of the next cycle, the ejection cylinder and the pin were retracted, the punch was pushed back to the squeeze casting position and secured in place, the stripper plate retaining screws were screwed into the die block, and then all the die cavity areas were coated with a mold wash. The dies were closed and, if necessary, reheated while the charge was being melted for the next cycle.



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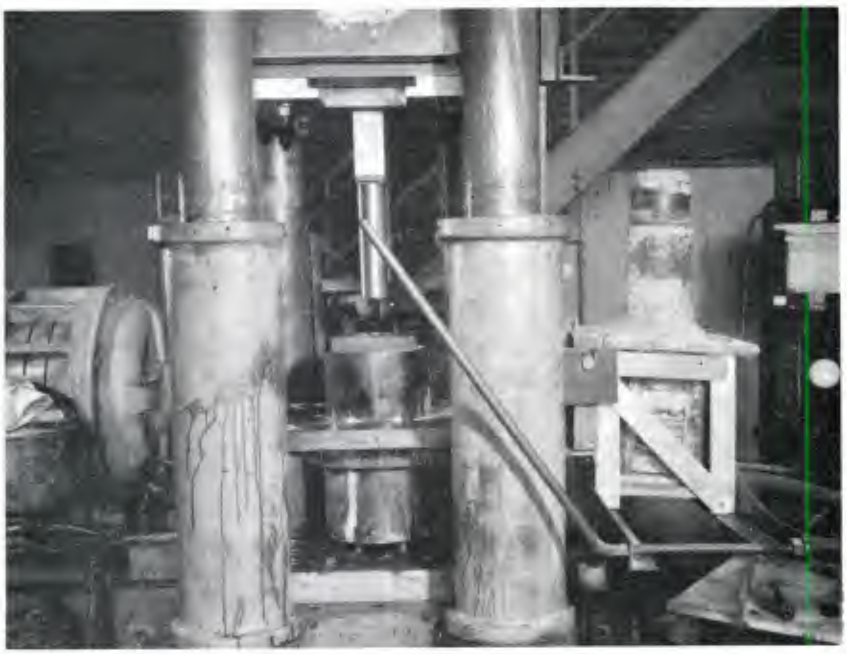

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Figure 14

Two Views of Barrel Support Die Set Mounted in Press. (Note the long cylindrical part of the punch and in Fig. 14b the induction melting furnace mounted on the press frame.

5. SQUEEZE CASTING SERIES AND TOOLING PERFORMANCE AND MODIFICATIONS

This section presents the details of the various experimental conditions used during the experiments, observations during the squeeze casting series, and the tooling performance and modifications. Improvements in the test procedure that were incorporated during the work are also described. The quality of the squeeze castings is referred to only to the extent that it influenced the various tooling modifications. Detailed evaluation of the squeeze castings is the subject of Sections 6 and 7.

5.1 Receiver Base Die

5.1.1 Observations During First Squeeze Casting Series

The melt was introduced into the squeeze casting die a total of 51 times in separate runs. In some cases the melt was allowed to solidify without application of pressure either to try out the procedure or because of some minor experimental difficulties. Hence, 45 receiver base squeeze castings resulted. Included in the study were variations of composition, melt volume, die temperature, melt temperature, press load, load duration, ram speed, furnace configuration, die design, and part design. Table 3 gives the main experimental conditions and Fig. 15 shows the excellent detail obtained on the squeeze castings.

The receiver base die functioned well; no major cracks developed, the use of standard Allen screws for assembly proved satisfactory, the simplicity of the die design permitted easy maintenance, and the two separate ejection pins activated by a single ejection ram were satisfactory. However, two serious die material related problems occurred.

First, the Anviloy punch cracked and deformed during squeeze casting. The deteriorated Anviloy punch, as shown in Fig. 16, created a larger bottom die cavity to punch clearance at the ends of the die cavity. This permitted molten steel to spray out of the die and a thick flash to develop at the ends of the squeeze casting. The heavy flash absorbed some of the load during squeeze casting which increased the possibility of porosity and also increased the force required to open the dies. This put extra load on the die-to-press retaining screws causing some to fail. Also, the deformed Anviloy punch made squeeze casting to net dimensions impossible.

Table 3

SQUEEZE CASTING OF RECEIVER BASE - SERIES I

Exp. No.	Melt Weight, lb	Bottom Die Temp., °F	Melt Temp., °F	Load, tons	Load Duration, sec	Press Speed, ipm
B1	10.0	550	2900	0	0	0
B2	10.0	780	2975	0	0	0
B3	8.0	840	2925	150	2	35
B4	9.0	-	2900	150	2	35
B5	10.0	750	2900	0	0	0
B6	10.0	750	2900	150	2	30
B7	10.5	620	2900	150	2	30
B8	10.5	620	2850	150	2	30
B9	11.0	600	2900	220	5	30
B10	11.0	600	2900	220	5	30
B11	11.0	600	2950	220	10	40
B12	11.0	800	2950	220	10	60
B13	11.0	700	3000	220	10	600
B14	11.0	700	3050	220	10	600
B15	11.0	760	2900	0	0	0
B16	11.0	700	3000	220	10	600
B17	11.0	650	2950	220	10	600
B18	11.0	600	2950	220	30	600
B19	11.0	-	2950	220	30[a]	600
B20	11.0	650	2950	220	30[a,b]	600
B21	11.0	650	2950	220	30[a,b]	600
B22	11.5	850	2950	220	30[a,b]	600
B23	11.5	-	2950	220	30[a,b]	600
B24	11.5	-	2950	220	30[a,b]	600
B25	11.5	600	2950	220	30[a,b]	600
B26	11.5	-	3000	220	30[a,b]	600
B27	11.5	850	2950	220	30[a,b]	600
B28	11.5	900	2950	220	30[a,b]	600
B29	11.5	-	2950	220	30[a,b]	600
B30	11.5	800	2950	220	30[a,b]	600
B31	11.5	900	2950	220	30[a,b]	600
B32	11.5	800	2950	220	30[a,b]	600
B33	11.5	680	2950	220	30[c]	600
B34	11.5	750	2950	220	30[c]	600
B35	11.5	650	2950	220	30[c]	600
B36	11.5	-	2900	220	30[a]	600

Table 3 (cont.)

Exp. No.	Melt Weight, lb	Bottom Die Temp., °F	Melt Temp., °F	Load, tons	Load Duration, sec	Press Speed, ipm
B37	11.5	550	2900	220	30	600
B38	11.5	-	2900	220	30	600
B39	11.5	-	2900	0	0	0
B40	11.5	-	2900	0	0	0
B41	11.5	450	2900	220	30	600
B42	11.5	650	-	220	30	600
B43	11.5	-	2900	220	30	600
B44	11.5	650	2900	220	30	600
B45	11.5	650	2930	220	30	600
B46	11.5	680	2930	220	30	600
B47	11.5	-	2900	220	30	600
B48	11.5	-	2900	220	30	600
B49	11.5	450	2950	220	30	600
B50	11.5	620	2950	220	30	600
B51	11.5	> 600	2940	220	30	600

[a] Dies remained closed for 30 sec after relaxation of load; others die opened immediately.

[b] Squeeze casting slowly cooled for 120 sec after opening die prior to ejection; force cooling with compressed air for some of the others.

[c] Dies remained closed for 120 sec after relaxation of load; for others die was opened immediately.

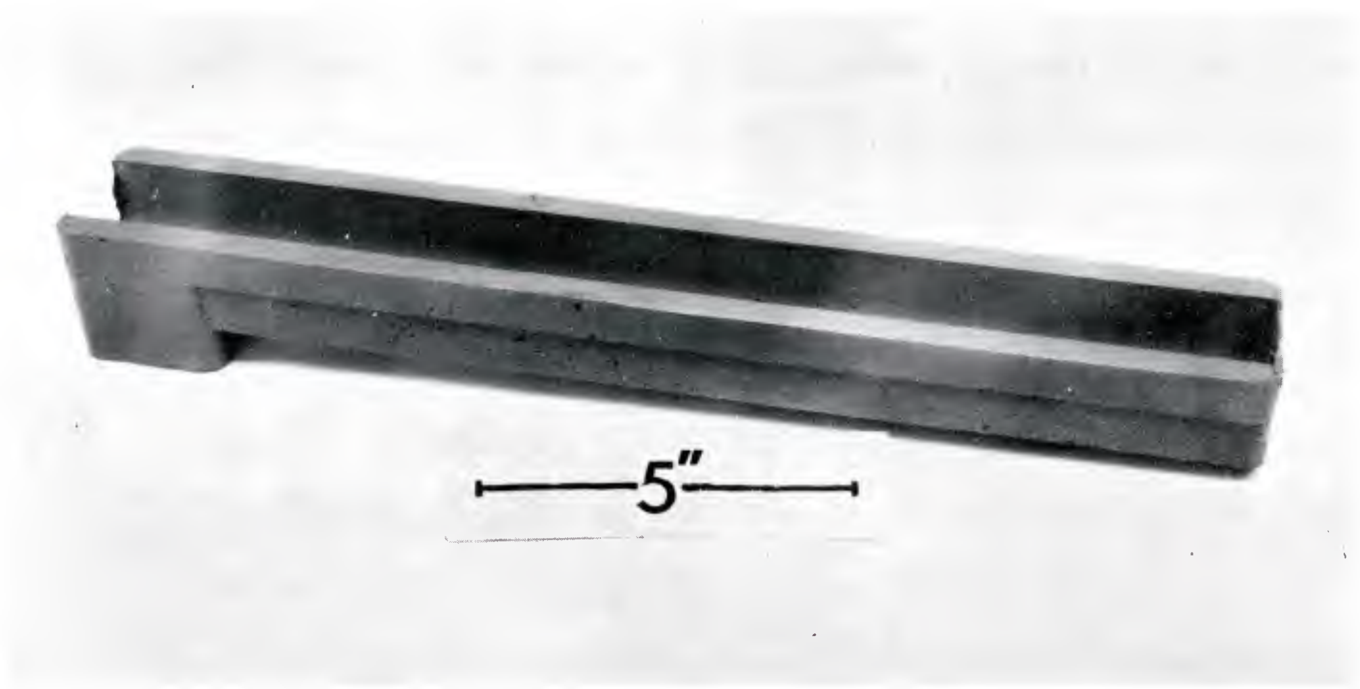

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Figure 15

Squeeze-Cast Receiver Base Made in an Initial Trial

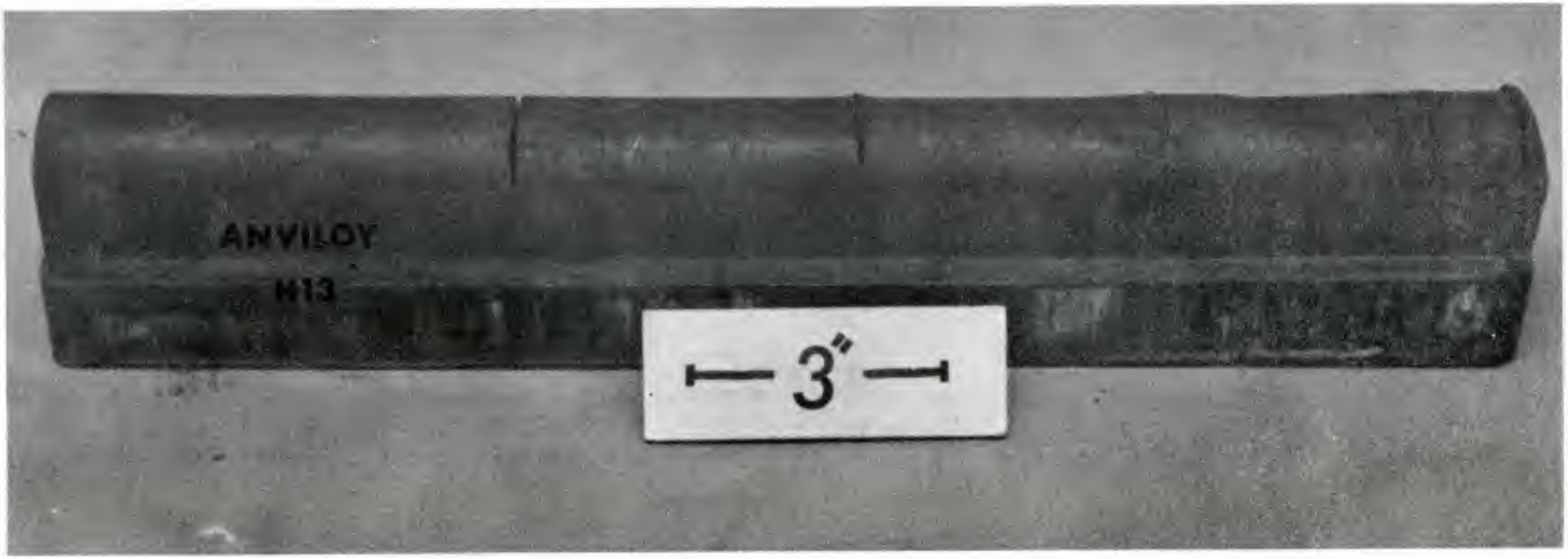

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Figure 16
H13 Punch Support with Anviloy Inserts after 45 Receiver Base Squeeze Castings.

Second, the walls of the H13 bottom die deformed as schematically shown in Fig. 17. This deformation created backdraft in regions which increased the required ejection force and made it very difficult to eject the squeeze casting without bending. In some experiments where a minimal amount of mold wash was used, welding occurred between the squeeze casting and the bottom die in the small region that the incoming stream of molten metal impinged on during pouring. Because of such welding and the deformed walls in the bottom die, the total required ejection force occasionally exceeded the available capacity of about 20 tons. In this case, the press (with a maximum capacity of 250 tons) was used to indirectly apply a greater load to the ejection pins. This procedure dislodged the squeeze casting, but it also excessively loaded the ejection components causing some bending of the ejection pins and some local deformation of the ejection yoke.

Other but less serious problems related to die material included some shallow cracks in the deformed regions of the H13 bottom die walls (as illustrated in Fig. 17), small cracks and erosion of the bottom die around the copper chill (the copper chill was added as a die modification and is discussed in Section 5.1.2) and adjacent areas, and cracking of the Anviloy insert.

The fine cracks around the copper chill can be seen in Fig. 18. The area between the chill and the ejection pin hole, in Fig. 18, shows some erosion and cracking because with the preferred pouring technique discussion in Section 4.3, the incoming stream of molten steel impinged on this area. The erosion and cracking were minor and should not affect the anticipated long die life.

Also shown in Fig. 18 is the cracked Anviloy insert. Although the cracks extended through the section thickness of the insert, the pieces remained in place in the die cavity and did not interfere with the use of the die.

5.1.2 <u>Tooling Modifications</u>

This section first describes the minor modifications attempted in the course of the first series and then details the major die changes incorporated just prior to the final series. The former included extending the punch and die cavity length, adding a copper chill to the bottom die, adding additional fasteners to retain the broken Anviloy punch inserts, and remachining the Anviloy inserts.

The initial squeeze castings were shorter than anticipated. Apparently the shrinkage factor applied to the die

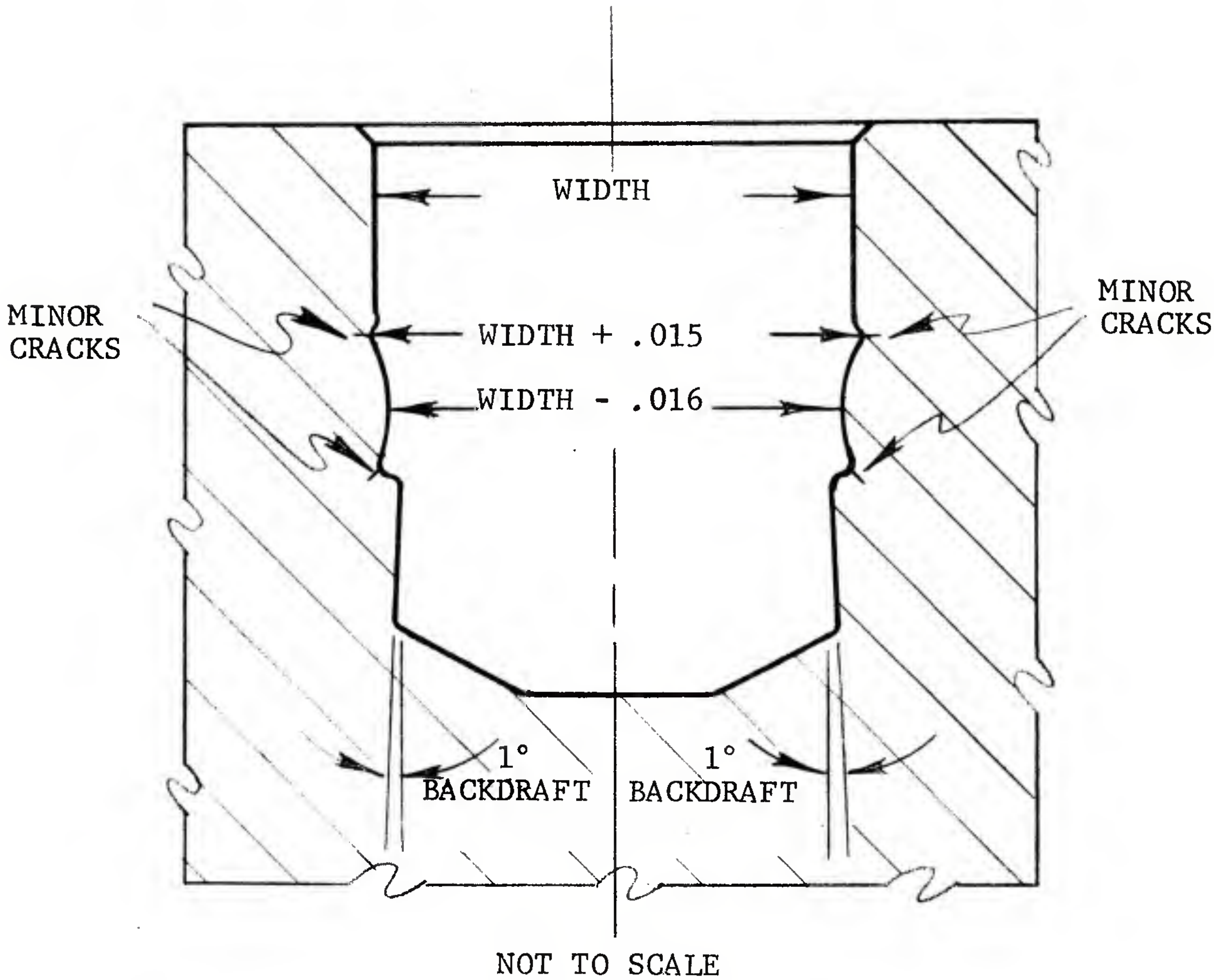


Figure 17

Cross Section of Receiver Base Bottom Die
Showing Location of Deformation and Minor Cracks.

Neg. No. 40231

Figure 18

Plan View of H13 Receiver Base Bottom Die Showing Cracked Anviloy Insert (A) and the Cracked and Eroded Area Between the Ejection Pin Hole (B) and the Copper Chill (C).

design, as discussion in Section 3.3.2, was too small. Instead of an as-cast length of 17.38 ± 0.01 in., the length was 17.27 in. which was only marginally enough for finish machining. Therefore, the bottom die cavity was extended at the deep end by 0.27 in. with conventional machining without annealing the die block. The punch was extended a similar amount by welding to it a heat-treated piece of H13 steel with the final punch-to-die clearance machined to 0.007 in. per end.

In some heavy sections such as the end of the receiver base, it becomes difficult to transmit pressure during solidification of the center of the section, because the thinner sections of the casting have by that time solidified completely. This caused some porosity in the heavy end (Section 6.2). To correct this, a copper chill (Fig. 18) was added in the bottom die. It was expected that solidification in the (thick) region of the chill would proceed at a faster rate and thereby equalize the time needed for complete solidification of the thick and thin sections. But the anticipated influence of the chill did not occur, probably because the chill size that could be accommodated was inadequate.

After the deformation and cracking of the Anviloy punch occurred, it was apparent that producing a receiver base squeeze casting with net surfaces was impractical at this stage with the existing dies. Therefore, the sides of the Anviloy punch were remachined to reduce the width by 0.03 in. to provide extra material on the squeeze casting as a machining allowance. The cracked and distorted condition of the Anviloy inserts and distortion of the H13 punch support also made some repair work necessary. Some new holes were drilled into the top plate (Fig. 5) which permitted first mounting the H13 punch tightly against the top die platen and then mounting the Anviloy inserts using new access holes.

Thirty more squeeze castings were made in the first series with the repaired and modified Anviloy punch. But the squeeze casting ends had an objectionable amount of flash and some surface irregularities. Also, the punch continued to deteriorate making it unsuitable for further use. Therefore, a new punch of H13 steel was designed and fabricated. This punch design, shown in Fig. 19, incorporated water cooling to limit the maximum temperature that the punch would reach during squeeze casting and to provide maximum cooling of the squeeze casting. Long punch life should be possible with the H13 component if the temperature during squeeze casting were kept below its tempering temperature of 1200°F. Ideally, the H13 punch would not soften and the thermal

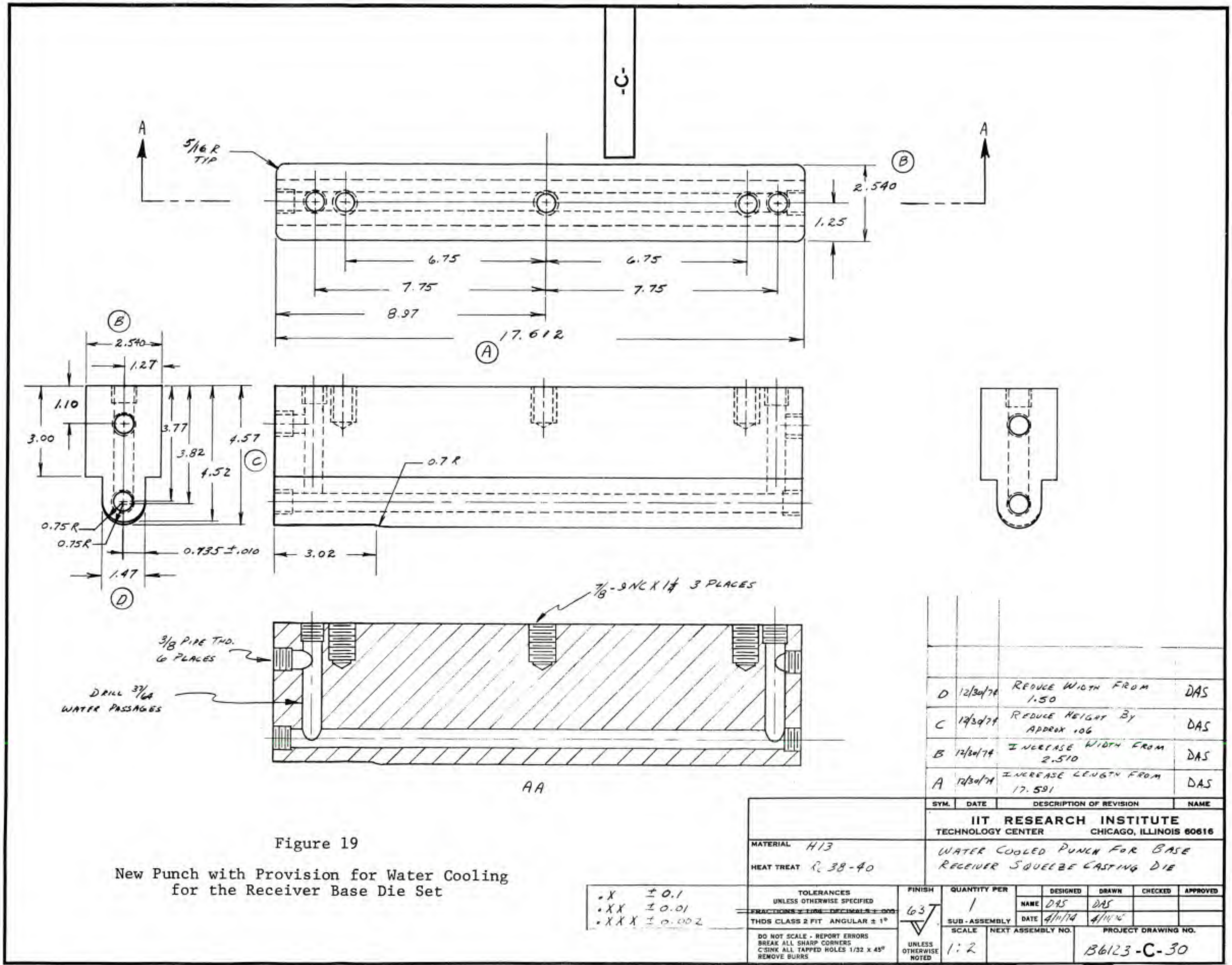


Figure 19

New Punch with Provision for Water Cooling
for the Receiver Base Die Set

cycling could be reduced to approximately a 400°F range, which would reduce thermal fatigue effects.

The major tooling modification incorporated after the first series was the provision of two auxiliary cylinders into the bottom die. The purpose of this modification was to eliminate the large local porosity that occurred in the heavy end of the squeeze casting because it became apparent that the small copper chill or a high squeeze casting pressure of 20,000 psi would not eliminate the porosity.

The two auxiliary cylinders, in effect, gave double-acting capability to the press. The purpose was to be able to apply pressure at the thick end of the receiver base independent of the main press tonnage. Although the addition of cylinders appears simple, the severe limitation of the open height in the 250-ton press and lack of any space below the main bolsters necessitated much work for design of a special base that could incorporate the small hydraulic cylinders for auxiliary load application and also support the squeeze casting die set. This base, shown schematically in Fig. 20, was positioned between the bottom bolster of the press and the squeeze casting die set proper. Two hydraulic cylinders were provided since they could also function as ejection pins for removing the casting from the die set. The two hydraulic cylinders each had a bore diameter of 3 1/4 in. and stroke of 4 in. At the hydraulic system pressure of up to 2000 psi, a maximum load capacity of 8 tons is obtainable applied by a 1.5 in. diameter pin, which corresponds to approximately 9,350 psi pressure on the squeeze casting. Thus, the auxiliary cylinders give a capability for applying this level of pressure at the thick end independent of the main press tonnage.

Some maintenance work was also carried out on the bottom die which suffered deformation (Fig. 17) because of the high pressure utilized in the first squeeze casting series. The deformation caused some backdraft on the vertical side walls of the bottom die. This could be readily corrected for by machining back the side walls slightly and correspondingly increasing the overall width of the new punch. This modification caused an increase of approximately 0.015 in. in the wall thickness of the squeeze casting.

The porosity noticed in the heavy end was also partially related to the sharp corner in some sections of the bottom die. These were modified by welding with a Xuper No. 860 CGS rod manufactured by Eutectic Corp., Flushing, N.Y., and then remachining in this corner. It is important to mention that this modification was carried out without any necessity

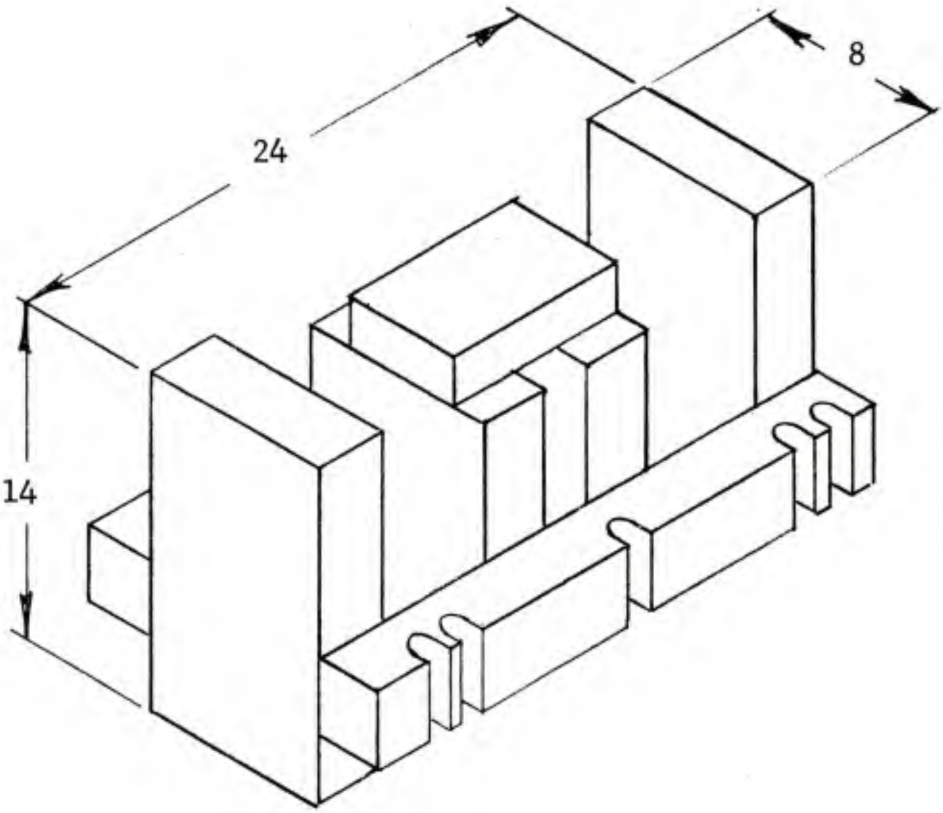


Figure 20

Special Base Fabricated to Incorporate Auxiliary Hydraulic Cylinders in the Receiver Base Die Set for the die set to be annealed and reheat-treated. This points out the ease of minor repairs in the squeeze casting die sets when they are made from die steels. This is important from a production standpoint where such minor repairs may be needed occasionally.

5.1.3 Final Squeeze Casting Series

Table 4 summarizes the experimental conditions used for the entire casting series. The main variables were the technique of application of the auxiliary load and duration of pressure. A number of tests were carried out without the application of the auxiliary pressure for reference points. The basic experimental procedure was very similar to that used earlier. The process parameters that were different included the punch temperature, the pressure level, and its duration.

The punch made from the die steel was preheated to a lower temperature of only about 130°F as against previously used temperatures of 600° to 700°F for the Anviloy punch. This was done for two reasons: First, a somewhat low temperature was chosen for the punch since it was not known initially how well the die steel punch would withstand the squeeze casting operation with the rather unfavorable part geometry. Second, if water cooling were used, the punch could not be heated much beyond 200°F. On the other hand, if air cooling were used before closing the die in order to achieve a higher punch temperature, water cooling could not then be started for faster cooling after the dies are closed because of the danger of damage to the dies through thermal shock.

Even with the somewhat lower die temperature, it was expected that the cooling of the work material by the punch would be substantially slower with the new punch than with the Anviloy punch because the thermal conductivity of the die steel is only about one-quarter that of the Anviloy. In addition, whereas higher pressures had to be used with the Anviloy punch in an effort to close the porosity in the thick end, the added flexibility of applying the auxiliary pressure made such pressures unnecessary with the new punch. Consequently, squeeze casting trials were initiated with a lower pressure of only about 6,000 psi as against nearly 10,000 psi used with the Anviloy punch. As explained later, satisfactory quality squeeze castings could be made even with this substantially reduced pressure, and so this pressure was used throughout the series.

Table 4

SQUEEZE CASTING OF RECEIVER BASE - SERIES II

Exp. No.[a]	Melt Weight, lb	Bottom Die Temp., °F	Melt Temp., °F	Auxiliary Ram, tons	Duration of Load, sec
B54[b]	13.0	600	2850	0	5
55[b]	13.0	600	2950	0	10
56[c]	13.0	600	2940	7	10
57	12.5	600	2950	7	10
58	12.5	600	2950	7	10
59	12.0	600	2950	7	10
60	12.0	590	2950	0	10
61[c]	12.0	610	2950	7	10
62[d]	12.0	600	2950	7	10
63	12.0	615	2950	7	10
64	12.0	610	2825	7	10
65	12.0	400	2850	7	10
66	12.0	580	2950	7	10
67[e]	12.0	435	2850	7	10
72	12.0	600	2940	6	10
73[f]	12.0	600	2940	6	10
74	12.0	600	2940	6	10
75[d]	12.0	650	2950	8	7
76	12.0	700	2940	8	10
77	12.0	650	2950	8	10
78[d]	12.0	700	2950	8	10
79	12.0	650	2950	8	20
80	12.0	650	2940	8	20
81	12.0	600	2900	8	20
82	12.0	575	2940	8	20
83	12.0	600	2900	7	20
84	12.0	525	2950	7	20
85	12.0	525	2950	8	20
86	12.0	675	2950	8	20
88[e]	12.0	725	2950	8	20
89[e]	12.0	565	2900	8	20
90[c,e]	12.0	600	2890	8	20
91[e]	12.0	600	2950	8	20
92[f]	12.0	--	2900	8	20
93	12.0	575	2900	8	20
94[c]	12.0	650	2910	8	20

Table 4 (cont.)

Exp. No.[a]	Melt Weight, lb	Bottom Die Temp., °F	Melt Temp., °F	Auxiliary Ram, tons	Duration of Load, sec
B95	12.0	600	2900	8	20
96	12.0	600	2940	8	20
97	12.0	600	2940	8	20
98	12.0	600	2965	8	20
99	12.0	600	2975	8	20
100	12.0	600	2940	8	20
101	12.0	525	2950	8	20
102	12.0	600	2940	8	20
103	12.0	650	2940	8	20
104	12.0	600	2950	8	20
105	12.0	600	2940	8	20
106	12.0	600	2925	8	20
107	12.0	700	2950	8	20
108	12.0	550	2950	8	20
109	12.0	600	2925	8	20
110	12.0	650	2900	8	20
111	13.0	675	2900	8	20
112	13.0	650	2920	8	20
113	13.0	700	2900	8	20
114	13.0	550	2970	8	20
115	13.0	--	2900	8	20
116	13.0	650	2920	8	20
117	13.0	700	2900	8	20
118	13.0	700	2900	8	20
119	13.0	750	2920	8	20
120	13.0	600	2910	8	20
121	13.0	600	2940	8	20
122	13.0	600	2910	8	20
123	13.0	600	2925	8	20
124	13.0	600	2900	8	20
125	13.0		2900	6	5
126	13.0	600	2900	7	20
127	13.0	650	2900	7	20
128	13.0	700	2900		20

Table 4 (cont.)

Exp. No.[a]	Melt Weight, lb	Bottom Die Temp., °F	Melt Temp., °F	Auxiliary Ram, tons	Duration of Load, sec
B129	13.0	700	2900	7	23
130	13.25	800	2900		20
131	13.25	600	2900		20
132	13.25	600	2900	8	20
133[d]	13.25	1000	2900	8	20
134	13.25	650	2900	6	20
135	13.25	650	2900		
136	13.25	650	2900		20
137	13.25	650	2900	7	20
138	13.25	650	2900	7	20
139	11.73	650	2900	7	20
140	13.25	650	2900	8	20
141	13.25	650	2900	8	20
142	12.0	675	2900	8	20
143	12.0	650	2900	8	20
144[b]	12.0	650	2900	8	20
145	12.0	675	2900	8	20
147	13.25	600-650	2900	8	20
148	13.25	600-650	2900	8	20
149	13.25	600-650	2900	8	20
150	13.25	600-650	2900	8	20
151[c]	13.25	600-650	2900	8	20
152	13.25	600-650	2900	8	20
153	13.25	600-650	2900	8	20
154	13.25	600-650	2900	8	20
155	13.25	600-650	2900	8	20
156	13.25	600-650	2900	8	20
157	13.25	600-650	2900	8	20
158	13.25	600	2900	8	20
159	13.25	600	2900	8	20
160	13.25	600	2900	8	20
161	13.25	600	2900	8	20
162	13.25	600-650	2900	8	20
163	13.25	600-650	2900	8	20
164	13.25	600-650	2900	8	20
165[d]	13.25	600-650	2900	8	20
166	13.25	600-650	2900	8	20

Table 4 (cont.)

Exp. No.[a]	Melt Weight, lb	Bottom Die Temp., °F	Melt Temp., °F	Auxiliary Ram, tons	Duration of Load, sec
B167	13.25	600-650	2900	8	20
168	13.25	600-650	2900	8	20
169	13.25	600-650	2900	8	20
170	13.25	600-650	2900	8	20
171	13.25	600-650	2900	8	20
172	13.25	600-650	2900	8	20
173	13.25	600-650	2900	8	20
174	13.25	600-650	2900	8	20
175	13.25	600-650	2900	8	20
176	13.25	600-650	2900	8	20
177	13.25	600-650	2900	8	20

Note: 125 tons load; 600 ipm press speed, except as noted.

[a] B52, B53, B68, B69, B70, B71 - Melt pourint test, die not closed. B87 and B146 - run aborted due to minor problems.

[b] Stuck to punch.

[c] Squeeze casting bent during ejection.

[d] Stuck in die.

[e] Press speed, 60 ipm.

[f] Punch reworked before this test.

Initial squeeze castings made with the auxiliary cylinder had a depression formed by the auxiliary punch in the thick end of the squeeze castings. Since this depression made the squeeze casting unsuitable for machining, the auxiliary punch at the heavy end of the squeeze casting was shortened approximately 3/8 in. Additional squeeze castings made with the modified punch but retaining the hydraulic pressure at 1600 psi and 10 sec load duration had a projection protruding from the thick end of the squeeze casting conforming to the diameter of the auxiliary punch and nearly as long as the amount removed from the punch length. Increasing the hydraulic pressure to 2000 psi did not eliminate the projection. Increasing the load duration to 20 sec and using the 2000 psi hydraulic pressure did minimize the projection on the heavy end of the squeeze casting.

In this series, nearly 120 squeeze castings were made. The punch withstood the operation very well in that it did not suffer any catastrophic breakage. Local deformation and roughening of the surface was noticed, however, and it appears that, although the die steel may prove to be acceptable as the die material, selection of a better material would be desirable for the punch. The lower die withstood the series very well except that some local damage was seen around the ejection pin hole used in the previous series which was blocked when the new auxiliary cylinders were provided in the die system. The sides of the die showed slight damage which made it progressively somewhat more difficult to remove the squeeze casting from the die. As squeeze casting evaluation showed, the auxiliary cylinders proved to be very effective in eliminating the porosity in the thick end.

Some of the squeeze castings bent during retraction of the punch because of the binding of the casting around the punch or during ejection from the bottom die because only two small diameter ejection pins were used. In production, the first difficulty can be overcome by providing some draft on the punch unlike in this development program where the punch had no draft. The second cause of bending can be avoided by applying the ejection force over a longer length of the casting. Another minor difficulty was that the ejection pin stems suffered some bending and made it difficult to transmit the pressure whereupon a new set of stems was substituted.

5.2 Barrel Support Die

5.2.1 Observations during First Series of Tests

In the first series, Table 5, melt was introduced into the die 36 times and 25 squeeze castings were made. Castings with excellent overall definition, Fig. 21, were made within a few tests. The die performance was generally satisfactory, but a few shortcomings were apparent and suggested need for tooling modification.

The barrel support die design was proven to be practical. The double-acting feature functioned as intended, and the need to slide the punch assembly clear off the die to make room for ejection and the use of a bolted down stripper plate did not impede experiments. No large cracks or deformation developed in the H13 bottom die, Anviloy ejection pin, or H13 stripper plate.

Two major problems occurred with the barrel support die. The punch and punch body were damaged several times, and the mild steel plate supporting the Anviloy ejection pin was deformed. Both problems are due to the barrel support squeeze casting configuration; its long thin sections are difficult to displace molten metal into without premature solidification taking place.

Slow press speed, low pouring temperature, or low die temperature could cause premature solidification of the steel which would prevent the punch from fully entering the die. In this condition, the punch assembly can be excessively loaded resulting in bending or distortion of the punch and punch body.

In the initial experiments, the Anviloy punch was subjected to some bending during squeeze casting and during extraction. Because Anviloy has low ductility, the end of the Anviloy punch broke during squeeze casting No. A4 and again during squeeze casting No. A5. A new pin was then made from a modified A286 (nickel-base alloy) casting, which was supplied as melt stock and did not contain aluminum and titanium. The material proved to be totally inadequate and suffered severe barreling near the top end and also caused some damage to the rectangular portion of the punch support. The latter could, however, be readily remedied by welding and some finish machining.

An Inconel 718 casting made for the purpose of melt stock was obtained (from Cannon-Muskegon Corporation, Muskegon, Michigan), and a pin was machined from it. This material has

Table 5

SQUEEZE CASTING OF BARREL SUPPORTS - SERIES I

Exp. No.	Melt Weight, lb	Bottom Die Temp., °F	Melt Temp., °F	Load, tons	Load Duration, sec	Press Speed, ipm
A1[a]	12.0	680	2870	0	0	0
A2[a]	12.0	650	2930	0	0	0
A3[a]	12.0	780	2930	0	0	0
A4[a]	12.0	700	2930	45	5	37
A5[a]	14.0	700	2925	150	1	60
A6[b]	12.0	720	2925	150	5	60
A7	12.0	725	2925	0	0	0
A8	9.5	700	2925	125	5	37
A9	9.5	-	2950	0	0	0
A10	9.5	-	2950	150	5	60
A11	12.5	720	2950	150	3	60
A12	12.5	700	2950	150	1	600
A13	12.5	-	2950	150	1	600
A14	12.0	-	2950	150	1	600
A15	12.0	850	2950	0	0	0
A16	12.0	750	2950	150	1	600
A17	12.0	-	2950	150	1	600
A18	12.0	-	2950	0	0	0
A19	12.0	-	2950	150	1	600
A20	11.6	516	2950	0	0	0
A21	11.6	543	2950	0	0	0
A22	11.6	537	2950	0	0	0
A23	11.6	534	2950	150	8	600
A24	11.6	620	2950	150	8	600
A25	11.6	522	2950	150	5	600
A26	11.6	527	2950	150	5	600
A27	11.6	-	-	150	5	600
A28	11.6	533	3010	0	0	0
A29	11.6	667	2950	150	5	600
A30	11.6	720	3015	150	5	600
A31	11.6	718	3110	150	5	600
A32	11.6	638	3100	150	5	600
A33	11.6	618	2950	200	5	280[c]
A34	11.6	710	3000	200	5	315[c]
A35	11.6	728	3135	200	5	600
A36	11.6	716	3060	200	5	600

[a]Punch material Anviloy.

[b]A286; all others Inconel 718.

[c]Press speed timed during actual run; all others timed during press set-up prior to squeeze casting.

Neg. No. 40010

Figure 21

Squeeze-Cast Barrel Support Made in an Initial Trial fairly high hot strength, but its melting point is much lower than the work material. In the first casting, some welding was observed between the Inconel 718 pin and the work material. In subsequent tests, welding was eliminated by the application of the Markal CRT-22 coating described in Section 4.5. Deformation of the Inconel 718 punch was also prevented as long as the dies closed fully before solidification of the molten steel was completed.

In the die as originally designed, the Anviloy ejection pin (K, Figs. 9 and 10), which forms the lower end face of the barrel support, was not directly connected to the press ejection system and was supported by the lower mild steel plate (M) of the die set. Two problems developed after several squeeze casting trials in the first phase. The support shoulder of the Anviloy pin was marginally adequate at squeeze casting loads of 200 tons. This caused some minor deformation of the Anviloy pin and much indentation of the mild steel supporting plate (M). Second, the Anviloy pin was not directly connected to the press ejection system and had to be manually pushed down after each squeeze casting cycle. At first, the manual return of the pin was easy, but after some deformation of the pin and its support plate, the task became difficult and time-consuming.

It was found that the lower portion of the bore in the die body (E) had become pitted locally, making it difficult to remove the squeeze casting from the die. Since the bore in the lower die had no draft for a long length of 9 in., this was a major difficulty. There was some local deformation of the punch body (D) that directly supports the cylindrical portion of the punch (G). The usage of the largest possible diameter for Anviloy, known to be relatively weak in bending strength, caused the wall thickness of the H13 punch body to be quite small and, in some cases, the thin wall was pushed against the threads and caused a small backdraft. This made it, in turn, more difficult to retract the punch from the squeeze casting and open the dies.

In the squeeze casting operation, after the load is released, the press ram is retracted to remove the punch and the punch body from the squeeze casting, which is at that point held down into the lower die body (E) by the stripper plate (C). The retraction force available with IITRI's 250-ton hydraulic press is, at the most, 25 tons and this is quite marginal. After the load was released, the ram still could not be retracted for at least 8 more minutes during which time the squeeze casting shrank on the punch and the punch body; this was deemed to be a cause of cracking in the sharp corners and tube section of the barrel support squeeze casting. Although this problem results only from the limitation on the retraction force with IITRI's press, some technique had to be devised to overcome it to improve the product quality.

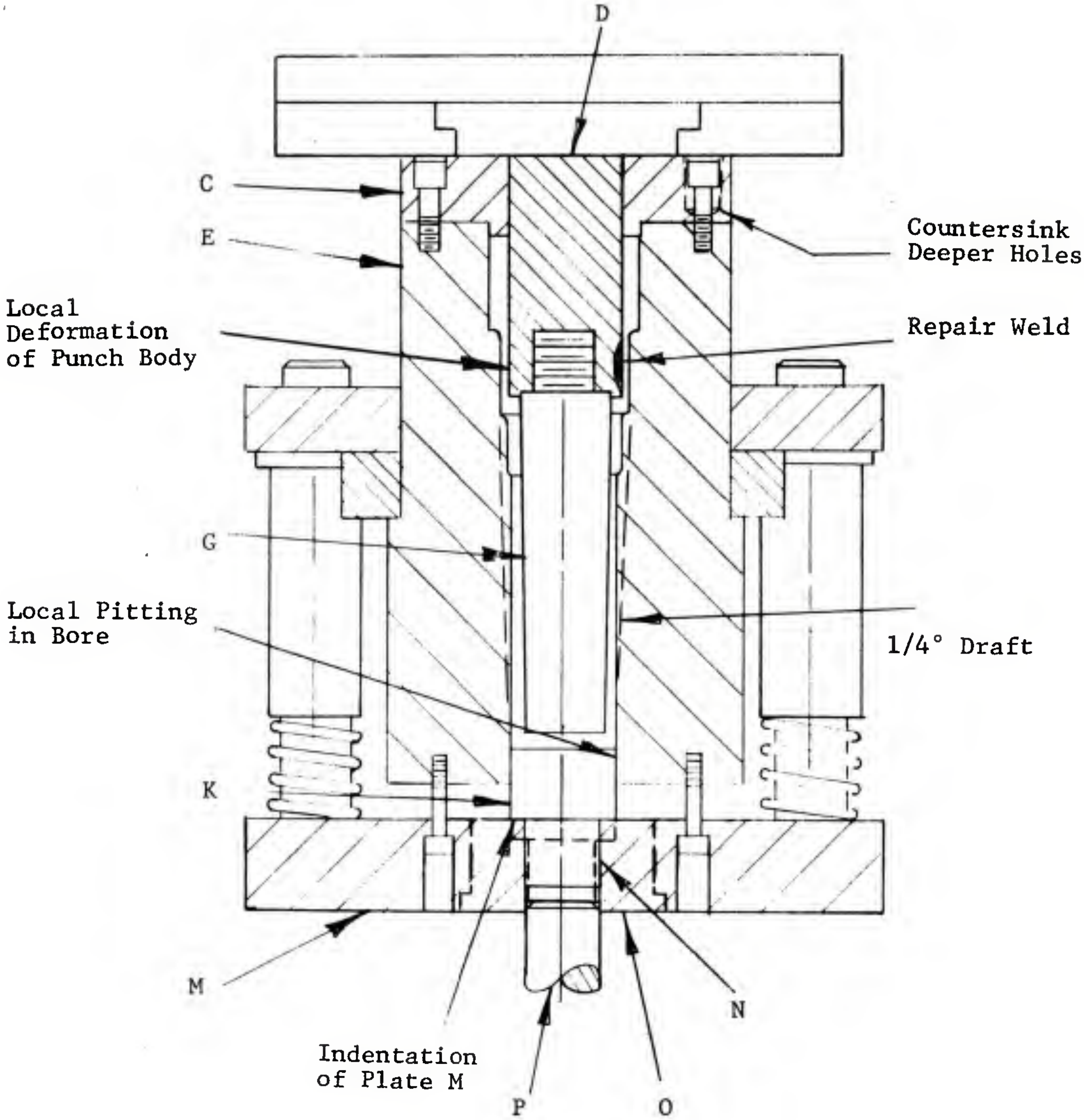
As described in Section 3.2.3, springs were to support the bottom die until the punch was fully inserted. Thus the springs had to be capable of applying enough force to overcome the friction force between the punch body and the stripper plate. Then the closed die should move down allowing squeeze casting pressure to be built up on the molten steel. Early experiments showed that the required spring force was quite high and beyond a practical spring size. An alternate method of achieving the same effect was to use sacrificial aluminum slugs to support the bottom die until the dies are fully closed. When the load exceeds the yield stress of the aluminum blocks, the closed dies move down as an assembly on the ejection pin. This technique was employed in all the subsequent tests.

5.2.2 Tooling Modifications and Second Series

This section describes the tooling modification made to the existing die set after the first series, details of the second squeeze casting series, and major tooling modifications after the second series. The purpose of the second squeeze casting series was to see whether defect-free squeeze castings can be reproducibly made without extensive changes in the tooling. In particular, attempts were made to produce squeeze castings comparable in quality to the best squeeze castings produced in the previous series. The tooling modifications were made to overcome the problems discussed in Section 5.2.1, and can be explained with the help of Fig. 22.

The problems of indentation of the lower plate (M) and difficulty in pushing back the ejection pin (K) were overcome by design and fabrication of two new components. An H13 ejection pin shaft (N) was made connecting the ejection pin to the press ejection system (P) and also had a large load-bearing surface for the ejection pin. To accommodate the ejection pin and new shaft, an H13 insert (O) was also made. This insert had three important functions: First, it had adequate strength to support the ejection pin and H13 ejection shaft at loads as high as 250 tons. Second, it replaced the damaged area in the mild steel plate (M). Third, it was necessary to have a removable insert to allow assembly of a die set incorporating retraction of the ejection pin.

To eliminate the roughened areas on the bore of the die body (E) and to ease squeeze casting removal, the bore of the



C - Stripper Plate
D - Punch Body
E - Die Body
G - Punch
K - Ejection Pin
M - Lower Plate of Die Set
N - Ejection Pin Shaft
O - Insert
P - Press Ejection Shaft

Figure 22

Barrel Support Die Assembly Showing Modifications and Reasons for Them. (Modifications shown in dashed lines.)

die was modified. The diameter of the bore at the bottom end was increased to remove the pitting, and the bore area above the ejection pin (K) was given a 1/4° draft. The diameter of the Anviloy ejection pin was increased by welding and machining to the new diameter of the die. Deformation of the punch body (D) over the threads of the punch (G) was corrected for by local welding of the depressed area and remachining. A more permanent solution was to increase the wall thickness of the punch body when an entirely new punch was made, as discussed later in this section.

To permit easier extraction of the punch from the squeeze casting, the stripper plate (C) was allowed to lift off the die (E) by approximately 1/4 in. This permitted the punch, squeeze casting, and stripper plate to move up 1/4 in. upon reversal of the ram after relaxation of the squeeze casting pressure. Since the bore area of the bottom die was drafted, the 1/4 in. movement released the squeeze casting from the bottom die. The punch was then retracted further to extract it from the squeeze casting, which was held down by the stripper plate. Basically, the technique separated the actions for releasing the casting from the bottom die and extracting the punch from the casting. The press ram retraction force of 25 tons was adequate in most cases for each of these two actions that now took place consecutively and not concurrently.

The stripper plate movement was achieved by first loosening the original screws. Although this gave the necessary amount of travel, the screw heads had to be reduced in height. Because the modified screw heads were weakened, they were replaced with flat head screws. The flat head screws required a modification to the counterbores in the stripper plate which resulted in a moving stripper plate with high-strength screws.

The experimental conditions for the second squeeze casting series are summarized in Table 6. In all, 34 castings were made, some of which were test runs carried out without application of the load. The experimental procedure was, in general, similar to that described before. The die assembly for these runs incorporated the modifications of retracting ejection pin, drafted die bore, and the loose stripper plate described in the previous section.

Test Nos. A37, A38, and A39 consisted of pouring the molten work material into the bottom die and allowing it to solidify without closing the dies. These test runs were undertaken as a quick check on the setup after the die modifications. Test Nos. A57 and A59 were aborted because of some minor equipment malfunction. In all, then, 29 squeeze castings were made

Table 6

SQUEEZE CASTING OF BARREL SUPPORT - SERIES II

Exp. No.[a]	Melt Weight, lb	Squeeze Casting Weight, lb	Bottom Die Temp., °F	Melt Temp., °F	Remarks
A40	12.50	12.00	775	2975	Easy retraction of punch
41	12.50	11.90	775	2975	Easy retraction of punch
42	13.00	12.94	800	2975	
43	13.00	12.77	800	3000	
44	13.00	12.88	800	3000	
45	13.00	12.54	800	3000	
46	13.00	12.42	850	2950	
47	13.00	12.42	800	2950	
48	13.00	--	800	2950	
49	13.00	12.02[b]	800	3100	
50	13.00	12.48	700	3050	
51	13.00	12.67	750	3050	
52	13.00	12.36	750	3025	
53	13.00	11.01[b]	800	3050	
54	13.00	11.78[b]	800	3050	
55	13.00	12.84	800	3000	No mold wash
56	13.00	13.34[c]	800	3025	
58	13.00	13.12[c]	700	3150	
60	13.00	12.02[b]	750	3050	
61	13.00	12.72	750	3050	
62	13.00	11.44[b]	750	--	
63	13.00	13.01	750	3050	
64	13.00	12.67	750	3050	
65	13.00	11.35[b]	750	3050	
66	13.00	12.07[b]	750	3050	
67	13.00	12.08[b]	750	3025	
68	13.10	12.74	750	3025	
69	13.45	11.94[b]	750	3025	
70	13.45	--	--	--	Punch damaged because ejection pin was in raised position

Note: 200 tons load; 5 sec load duration; 600 ipm press speed; 8 min delay to retract punch; alumina mold wash through Exp. No. 58, carbon soot as mold wash from Exp. No. 60 onwards except as noted.

[a] A37, A38, A39, A57, A59 - Melt pouring tests, dies not closed, i.e., made no squeeze casting.

[b] Squeeze casting weight reduction due to spray, skull, or an incomplete pour.

[c] Squeeze casting weight increase due to metal left in furnace from previous run.

during this series. The conditions common to all the squeeze castings were the load of 200 tons corresponding to a forging pressure of 28,000 psi, duration of application of load of nominally 5 sec, and press speed of approximately 600 ipm during free travel.

The weight of the melt for experiment No. A40 was estimated on the basis of the weight of casting A34 which was 11.6 lb plus addition of 0.9 lb for the increase in the volume of the die cavity because of the 1/4° draft angle added. Specimens A40 and A41, made with 12.5 lb melt weight, had an overall length that was 1/4 in. too short. Therefore, the weight was increased in the subsequent trials to 13 lb. For A40 and A41, it was possible to open the dies immediately after releasing the load. In all the subsequent cases, the ram could not be retracted for approximately 8 min after releasing the load.

The melt weight given in Table 6 is the weight of the melt stock that was loaded into the furnace. Usually, a thin layer of material remained in the furnace after it was tilted to pour the melt into the dies. Also, when the dies were closed, a small quantity of material was squeezed out through the clearances. Consequently, the weight of the as-squeeze-cast piece was generally about 0.6 lb less than the melt weight up to the melt weight itself. In two cases, A56 and A58, the squeeze casting weight was higher than the melt weight, apparently as a result of some of the melt stock remaining in the furnace from previous runs. Generally, any material remaining in the furnace could be and was removed easily after it solidified and prior to loading the material for the next run. In a few cases, a larger quantity of material remained in the furnace, probably as a result of the buildup in the furnace near the pouring spout. These specimens have been clearly identified in Table 6.

In the tests through A58, a commercially available ceramic mold wash, 839P, was utilized. This was sprayed into the bottom die cavity and on the punch. The deep cavity in the bottom die made it difficult to spray the wash uniformly and to observe any buildup on the die. With the buildup of the ceramic material, the surface of the squeeze casting became progressively coarser and more uneven. As discussed in Section 7.2, the ceramic buildup also caused some subsurface inclusions. A change of mold wash was made to improve the finish. In the squeeze casting tests starting from A60, carbon soot built up by using an oxyacetylene torch without oxygen was introduced as the mold wash. This technique was far more satisfactory in that inclusions were eliminated, it was easier to apply a uniform coat on the complex die cavity for the barrel support, and a substantial improvement occurred in the surface finish of the castings.

Tests A68, A69, and A70 were made with somewhat higher melt weight (for the reasons discussed in the next section, related to progressive removal of the buildup on the dies and the casting quality). This series showed a substantial improvement in ease of removal of the casting from the bottom die and general improvement in the procedure. However, the repeatability of the casting quality still did not show much improvement, and so the run was terminated. Also, in making casting No. A70, the punch was damaged beyond repair apparently because the ejection pin was in a raised position prior to pouring of the melt.

In the first two series, excellent quality--often nearly perfect--squeeze castings of the barrel support component were made. (See Section 7 for a detailed discussion of the quality achieved and the defects that still occurred.) However, some small defects such as cracks at the sharp corner radii on the inside of the rectangular portion persisted. The rectangular portions of the casting were sometimes free of porosity and sometimes not. In an effort to eliminate these remaining defects, to add a minimum but adequate amount of material where needed, and at the same time to make improvements in the ease of processing, several further modifications to the tooling were carried out.

The technique of assembling the cylindrical portion of the punch to the rest of the punch body was modified (Fig. 23) to allow a throughbolt from the other end of the punch body instead of threading the cylindrical part directly into the punch body. This permitted an increase in the minimum wall thickness of the punch body near the hole for the cylindrical portion and made the punch body considerably stronger. In addition, a small amount of draft was provided on the punch body (Fig. 24) corresponding to the inside of the rectangular parts of the squeeze casting, whereas in the past there was no draft in this area. The draft was added to make it easier to retract the punch from the squeeze casting and minimize the tendency of any hot tearing because of shrinkage of the cylindrical part of the casting on the Inconel 718 punch. A new punch connector plate (Fig. 25) was fabricated to support the punch body so that disassembly of the punch was possible if it became difficult to retract the punch from the casting.

The inadequate open height in the 250-ton press at IITRI made it necessary to retract the punch sideways prior to removal of the squeeze casting from the bottom die. In the past, several bolts had to be taken out and the punch had to be retracted manually with some difficulty. The new design of

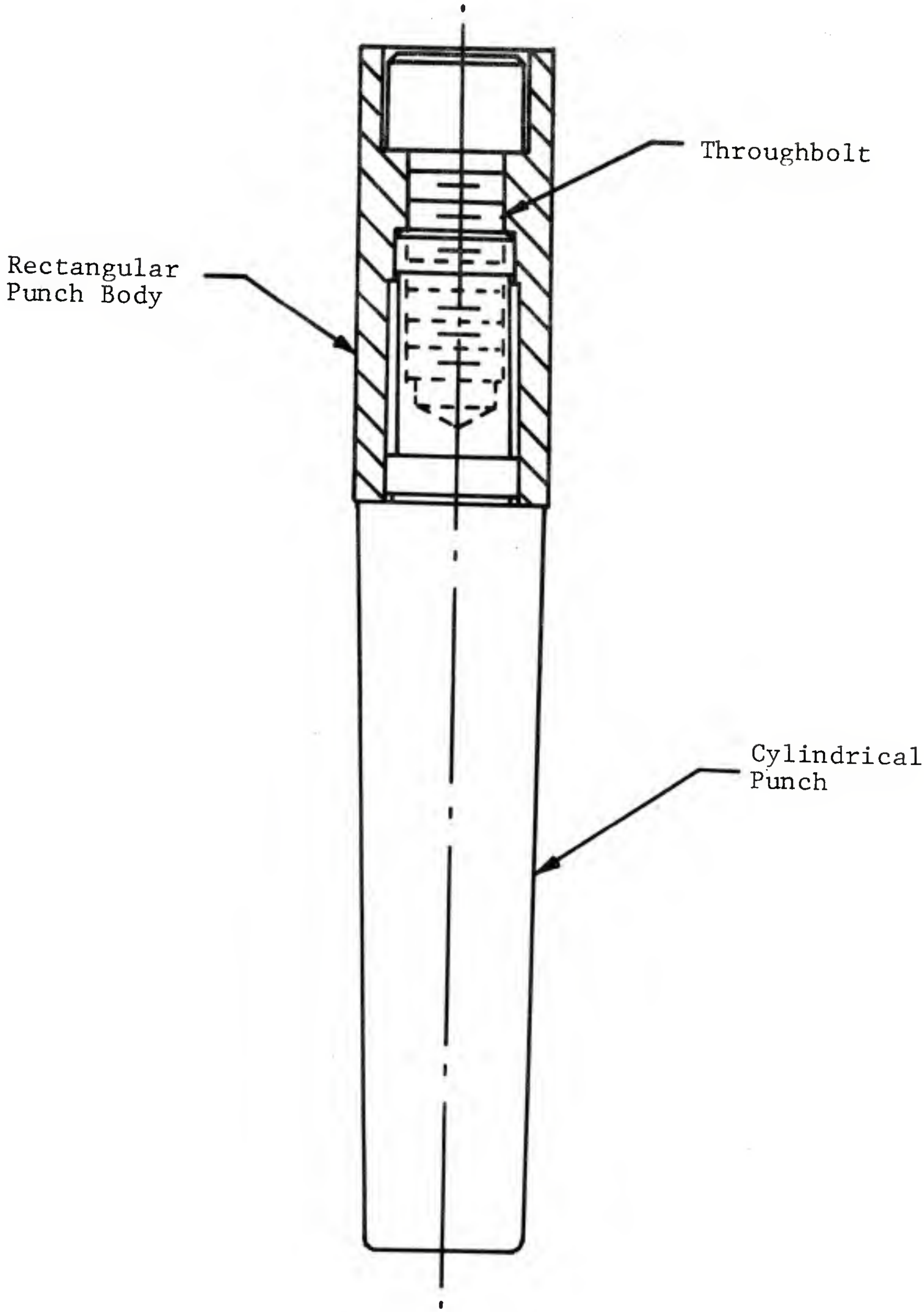
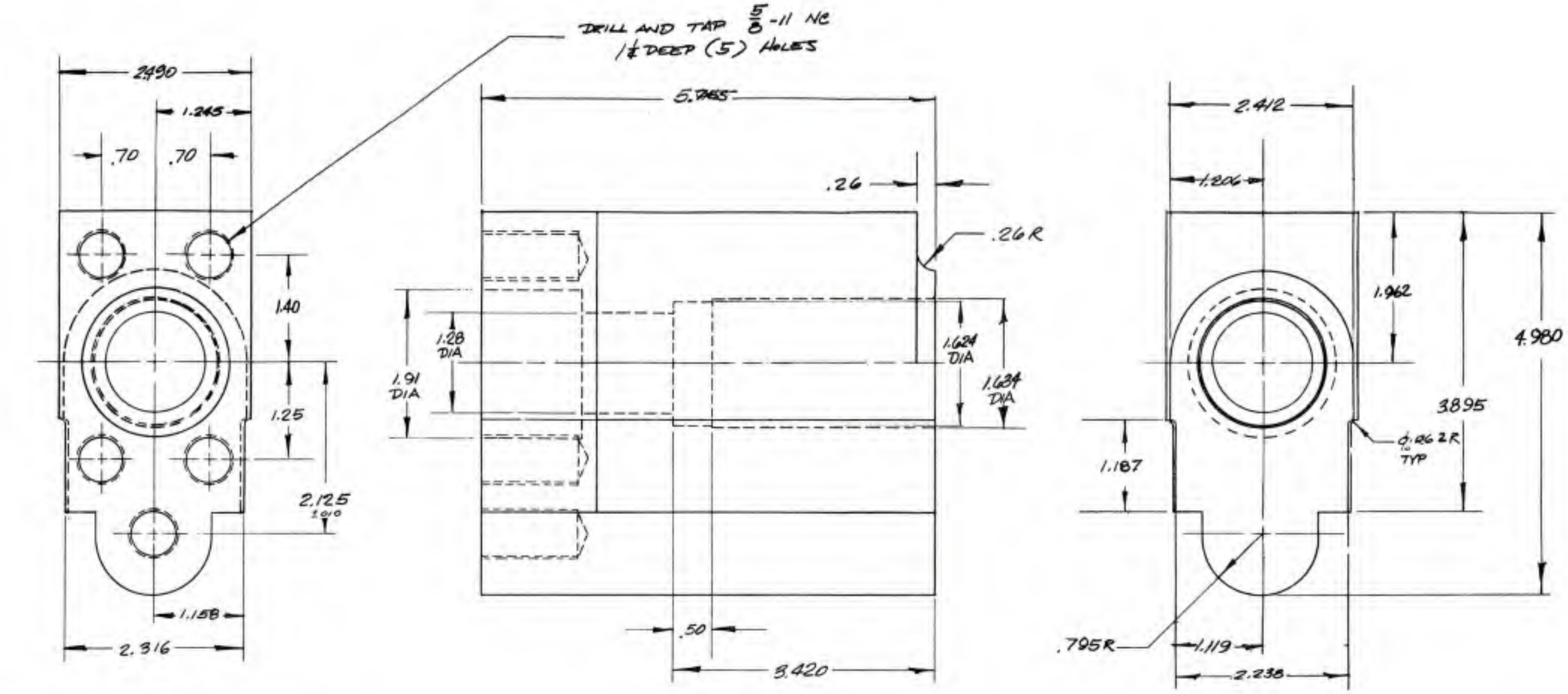


Figure 23

Method of Assembly of the New Punch
for Barrel Support Die Set



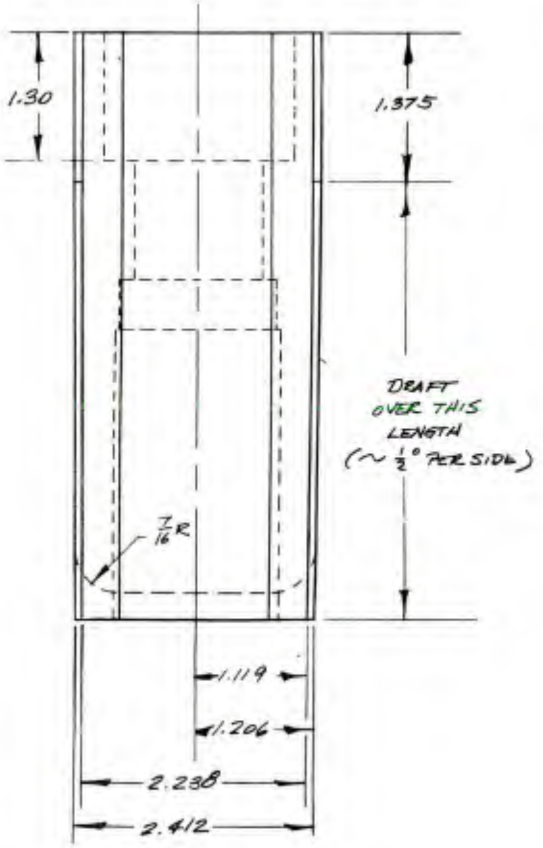
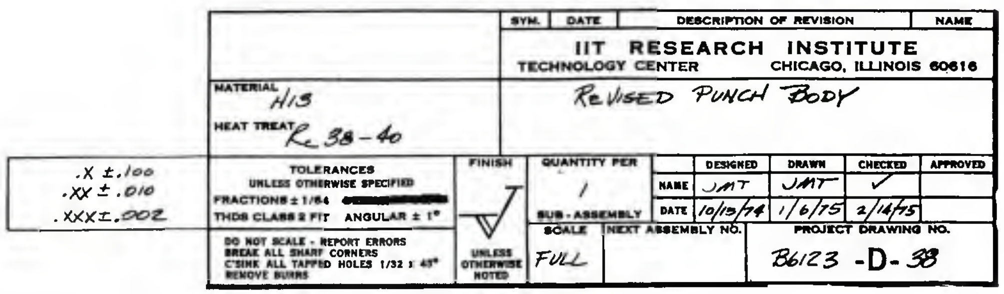


Figure 24

New Design of the Punch Body for Barrel Support Die Set



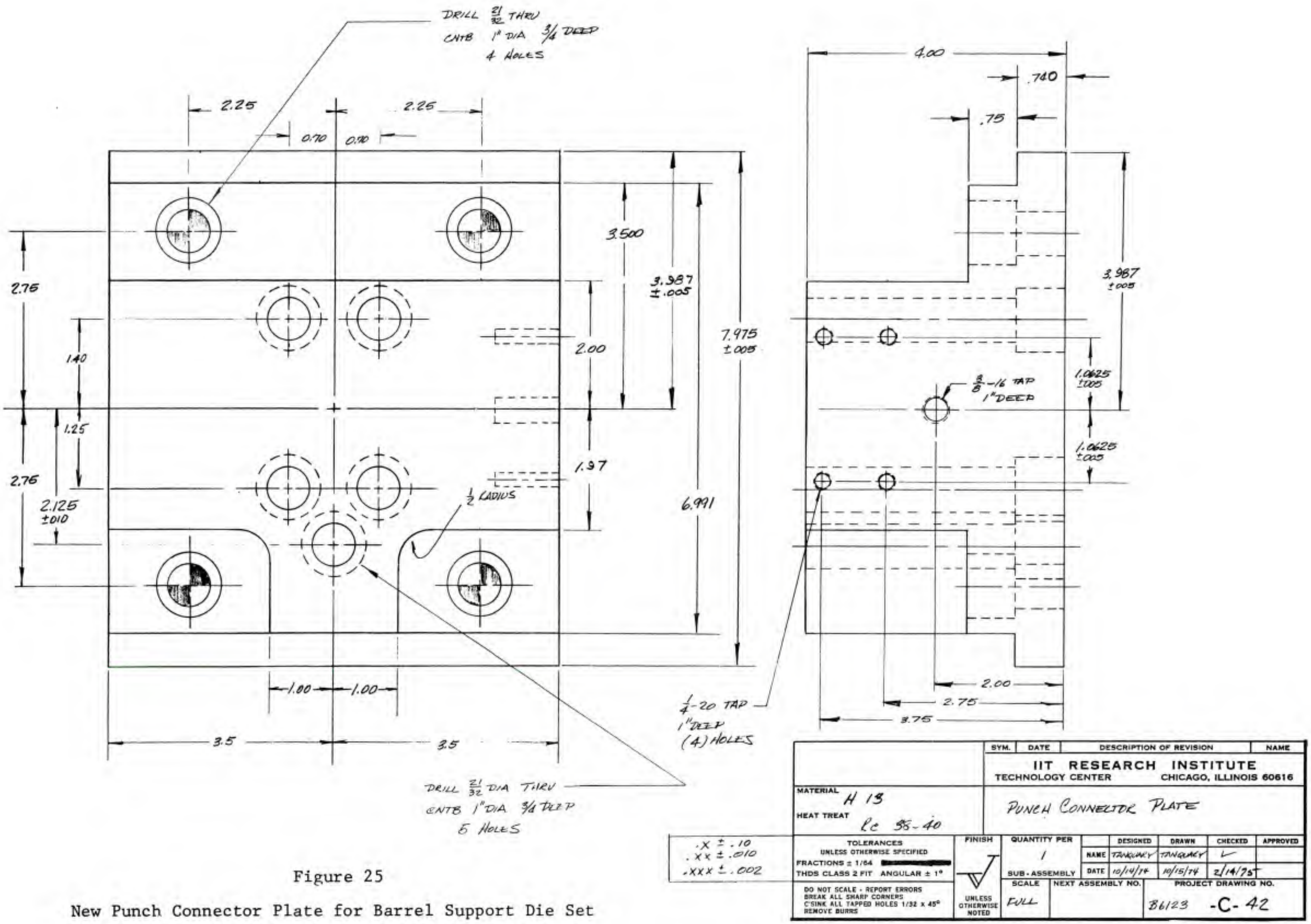


Figure 25

New Punch Connector Plate for Barrel Support Die Set the locator plate (Fig. 26) facilitated this lateral movement of the punch prior to removal of the squeeze casting from the bottom die.

The inside detail of the squeeze casting at the intersection of the rectangular portions and the cylindrical part was modified to increase the corner radii and provide some machining allowance to make the profile smoother and avoid various small steps corresponding to the geometry of the finish-machined component. This practically eliminated the cracking noticed in these corners (Section 7) in the past and also further aided in removing the punch from the squeeze casting.

In the first two series, in a vertical cross-section the wall thickness of the tube portion was larger towards the bottom than at the top. This happened because of the lower draft on the die compared to the punch. It was therefore decided to change this to make the draft the same on the die and the punch. This was to minimize any tendency for the centerline shrinkage in the tube section.

The porosity in the rectangular portion of the casting was difficult to eliminate consistently. This problem is related to relatively large section thickness in that portion of the casting compared to the tubular section of the casting and the long distance through which the metal must be pushed up to reach the rectangular parts of the casting. Instead of attempting to overcome this mainly by controlling the process variables, it was proposed to take advantage of the fact that shrinkage porosity occurs at the thermal center of a solidifying casting. Thus, if the machining allowance were such that the porosity occurs in a section that is machined off, the reproducibility could be increased substantially. The section thickness of the rectangular portion (Fig. 27) is highest along the center strip where the finish-machined component has a boss. There is already some machining on the squeeze casting in this area since undercuts cannot be formed in a simple die design. The section thickness of the part to be machined was increased further so that the porosity, if it did occur, should occur only in this section and the casting would be satisfactory for finish machining of the component.

5.2.3 Final Squeeze Casting Series

The tooling modifications incorporated after the second series had the expected benefits on the quality and the ease of processing in the subsequent squeeze castings in the third (Table 7) and fourth (Table 8) series. The squeeze castings

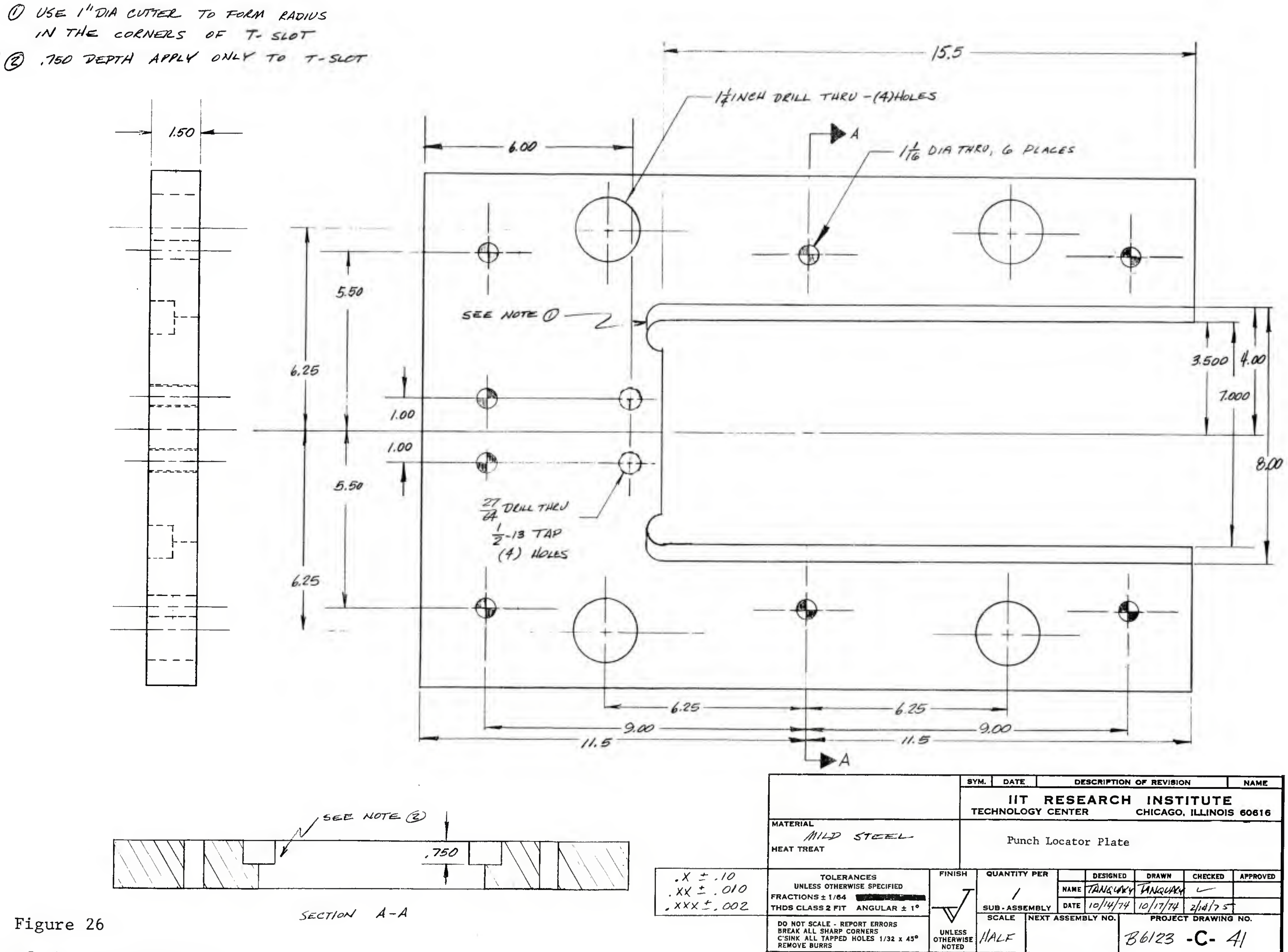


Figure 26

New Design of the Locator Plate for Barrel Support Die Set

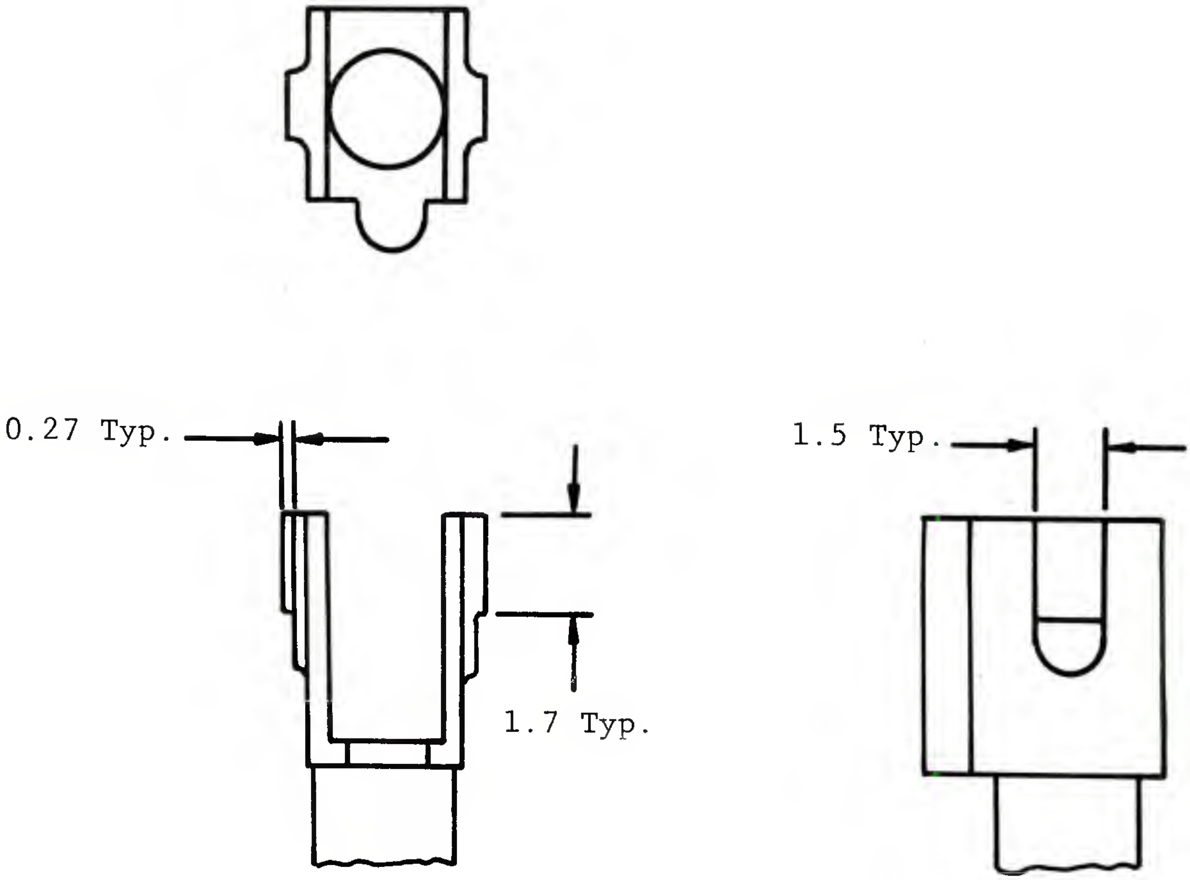


Figure 27

Schematic of the Modification for the Rectangular Portion of the Barrel Support Squeeze Casting

Table 7

SQUEEZE CASTING OF BARREL SUPPORT - SERIES III

Exp. No.	Melt Weight, lb	Bottom Die Temp., °F	Melt Temp., °F	Load, tons	Duration of Load, sec	Remarks
A74[a]	13.5	550	2950	200	∿5	
75	20	550	2950	200	∿5	
76	14.5	600	2975	200	∿5	Die stuck closed
77	14.5		2975	200	5	3 1/2 min[b]
78	14.5	700	2950	200	5	5 min
79	14.5		2950	200	5	4 min
80	14.5			200	2	4 1/2 min
81	14.5	600	3000	200	5	6 min
82		650	2950			7 1/2 min
83	14.5	600	2950	200	5	Let die set closed for 7 min before trying to open. Opened after ∿8 min
84	14.5	550	2975	200	5	
85						Test pouring. No load.
86	14.5	750	2950	200	20	Immediate
87	14.5	750	2950	200	20	5 min
88	14.5	750	2900	200	20	6 1/2 min
89	14.5	750	2950	200	20	7 min
90	14.5	700	2975	200	20	Stuck in die.
91						Could not pour into die because A90 stuck in cavity.
92	14.5	600	2950	200	5	10 min
93	14.5	600	2950	200	20	15 min
94	14.5	750	2950		0	No load built up.
95	14.5	625	2975	200	0	9 min

Table 7 (cont.)

Exp. No.	Melt Weight, lb	Bottom Die Temp., °F	Melt Temp., °F	Load, tons	Duration of Load, sec	Remarks
A96[a]						
97	14.5	600	2975	200	0	4 min
98	14.5	600	2950	200	0	11 min
99	14.5	650	2950	200	0	Stuck to punch.
100	14.5	600	2950	150	5	
101	14.5	750	2975	200	5	Part stuck in die.
102	14.5	850	2950	200	5	8 min
103	14.5	700	2900	200	5	4 min
104	14.5	600	2950	150	5	9 min
105	14.5	700	2950	150	5	Stuck in die overnight.
106	14.5	730	2950	150	5	Stuck overnight.
107	15	750	2950	200	5	6 min
108[c]	15.5	675	2950	200	5	Stuck in die
130	16.75	700-750	2900	150	5	Thermocouple did not work.
131	16.75	700-750	2900	150	5	5 min
132	16.75		2900			Thermocouple did not work.

[a] A71, A72, and A96 were test poured only. A73 initial casting test with 13 lb material and condition similar to A74.

[b] Time in remarks column refers to time required to open the dies after releasing the load.

[c] See Table 8 for A109 to A129.

Table 8

SQUEEZE CASTING OF BARREL SUPPORT - SERIES IV[a]

Exp. No.	Melt Weight, lb	Bottom Die Temp., °F	Melt Temp., °F	Load, tons	Duration of Load, sec	Remarks
A109	12.0					Pouring test.
110	12.7	700	2900	150	5	1st test with 1045 punch.
111	13.0		2900	150	5	
112	13.0	700-750	2900	150	5	
113	14.25	700-750	2900	150	1	Load released quickly because pouring spout broke and fell into die.
114	14.25	700-750	2900	150	5	Broke bolts that hold punch.
115	14.25	650	2900	150	5	
116	14.25	750	2900	150	5	
117	14.25	750	2900	150	5	
118	14		2900	150	5	
119	14	700-750	2900	150	5	First test with Inconel 713C punch. Die bolt broke.
120	14	700-750	2900	150	5	
121	14	700-750	2900	100	5	8 min[b]
122	14	700-750	2900	100	20	6 min
123	14	700-750	2900	100	20	6 min
124	14	700-750	2850	100	5	3 min
125	14	700-750	2800	100	5	1 min
126	14	700-750	2900	100	5	6 min
127	14	700-750	2900	100	20	6 min
128	14.5	700-750	2800	100	5	6 min
129	14.5	700-750	2800	100	5	8 min

[a]The entire series was conducted with punches 3 in. shorter than Inconel 718 punch used for other series. The melting furnace was modified with a thick steel spout instead of hand-made ceramic spout.
[b]Denotes time required to open dies after releasing load.

in Table 7 were made with the new Inconel 718 punch. The data in Table 8 are for squeeze castings made with somewhat shorter Inconel 713C and mild steel punches as part of the parametric study considering the effect of die material and squeeze casting geometry.

The experimental procedure was similar to that used in the previous series. All the experiments were conducted with carbon soot as the mold wash applied to the dies. As before, a ceramic mold wash was applied at the start of each series and periodically when it appeared that there was little ceramic coating left on the lower die. The carbon soot was built up after the ceramic coating was applied in such cases. The draft provided on the punch and the die made it easier to retract the punch from the squeeze casting and later to eject the squeeze casting from the lower die. However, because of the small magnitude of force available for punch retraction, in many squeeze castings it was still difficult to remove the punch immediately at the end of the squeeze casting operation. This caused cracking, normally longitudinal, on the squeeze casting because of its shrinkage on the rigid punch. Once again, this is a difficulty that should not be encountered in production with a press specially designed for the process.

With the new design of the punch (Fig. 23) and the revised punch body (Fig. 24), the problem of deformation of the punch body encountered earlier in the program was completely eliminated. Also, the new punch connector plate (Fig. 25) and punch locator plate (Fig. 26) permitted quick sideways movement of the punch to get it out of the way of the squeeze casting being ejected from the lower die and this made the overall processing much easier.

It is important to note that, in all, 40 squeeze castings were made with the new Inconel 718 punch during the squeeze casting series shown in Table 7. At the end of this series, the punch was totally free of any heat checks and any significant deformation. A very minor amount of upsetting was noticed only at the sharp lower corner of the punch. It is conceivable that with somewhat larger radius on the corner even this minor upsetting would not have occurred. The Inconel 718 was entirely satisfactory as a punch material, and its performance is truly remarkable in view of the severe service conditions that it must undergo. The combination of hot strength, ductility, and toughness in this material makes it an excellent candidate for such critical applications in squeeze casting. Furthermore, when used only for such small components, the overall contribution of the Inconel part of the die cost is insignificant. An excellent economic die system then results using H13 type of die steel dies with only a few small critical components made from such a superalloy. It is quite likely that, even in this severe application, the Inconel 718 punch can be expected to last several hundred or perhaps even several thousand squeeze casting operations.

The H13 die material was found to be entirely satisfactory as the material for bottom die and all the other major components of the die system. However, squeeze casting No. A108 stuck in the lower die, and in attempts to remove it some scoring resulted on the die wall. The inside diameter of the die increased by approximately 0.050 in. in cleaning up the die set. This was more a local failure of the mold wash and does not indicate any inadequate performance of the die material proper. Because of the thin flash extruded between the punch body and the stripper plate, some scoring was noticed on the punch body but did not pose any problem. No attempt was made to polish up these score marks, and they were merely covered by the carbon soot applied prior to each new experiment. In a production setup in long series, the tendency for scoring can be reduced by using a somewhat harder punch body and some type of surface treatment.

The squeeze castings in Table 8 were made with a shorter punch to study different die materials as well as to make a parametric study. No experimental difficulties were encountered in the course of these tests. A detailed evaluation of the results is presented in Section 7; however, it may be mentioned that these tests showed that even a common low-carbon steel can be used as a punch material where only a few squeeze castings are to be made. This in spite of the complex geometry of the barrel support. In all, ten experiments were conducted with the carbon steel punch which survived these operations very well. The only damage found was at the sharp corner at the junction of the punch and the punch body. Probably there was a small gap between the punch body and the punch at this junction, and the extrusion of the molten metal into this progressively damaged the sharp corner on the punch. More metal was then extruded into the larger gap and some tearing resulted on the inside of the squeeze casting. The mild steel punch was, however, still usable after making the ten squeeze castings. The Inconel 713C punch did not show any deformation after making 10 squeeze castings. But it did suffer some heat checking on the end face. Hence, Inconel 713C is inferior to Inconel 718 as a punch material for squeeze casting.

As discussed in Section 7.2, some porosity was found at the junction of the barrel section and the rectangular portions of the squeeze casting. This apparently resulted because the section thickness in this region was inadvertently increased because of the die modifications undertaken at the end of the second series. In particular, the larger radii on the inside of the rectangular portion and the elimination of the small steps in this area were responsible for this increase in section thickness. Our experience has shown that the squeeze casting process, even with a single-acting die system, can handle some variations in the section thickness quite well. But, in this particular case, the squeeze casting has a thin tubular portion and rectangular sections with a somewhat thicker section at the junction. It must have been difficult, therefore, to transmit the pressure through the thin rectangular portion of about 5 in. length down to the thicker section. In an effort to eliminate this porosity, minor modification of the punch body was attempted after casting No. A118, and some material was added back to the punch body at its junction with the punch by welding. (See comments on the results in Section 7.2.) Subsequent squeeze casting tests then proceeded without any serious difficulty.

6. EVALUATION OF RECEIVER BASE SQUEEZE CASTINGS

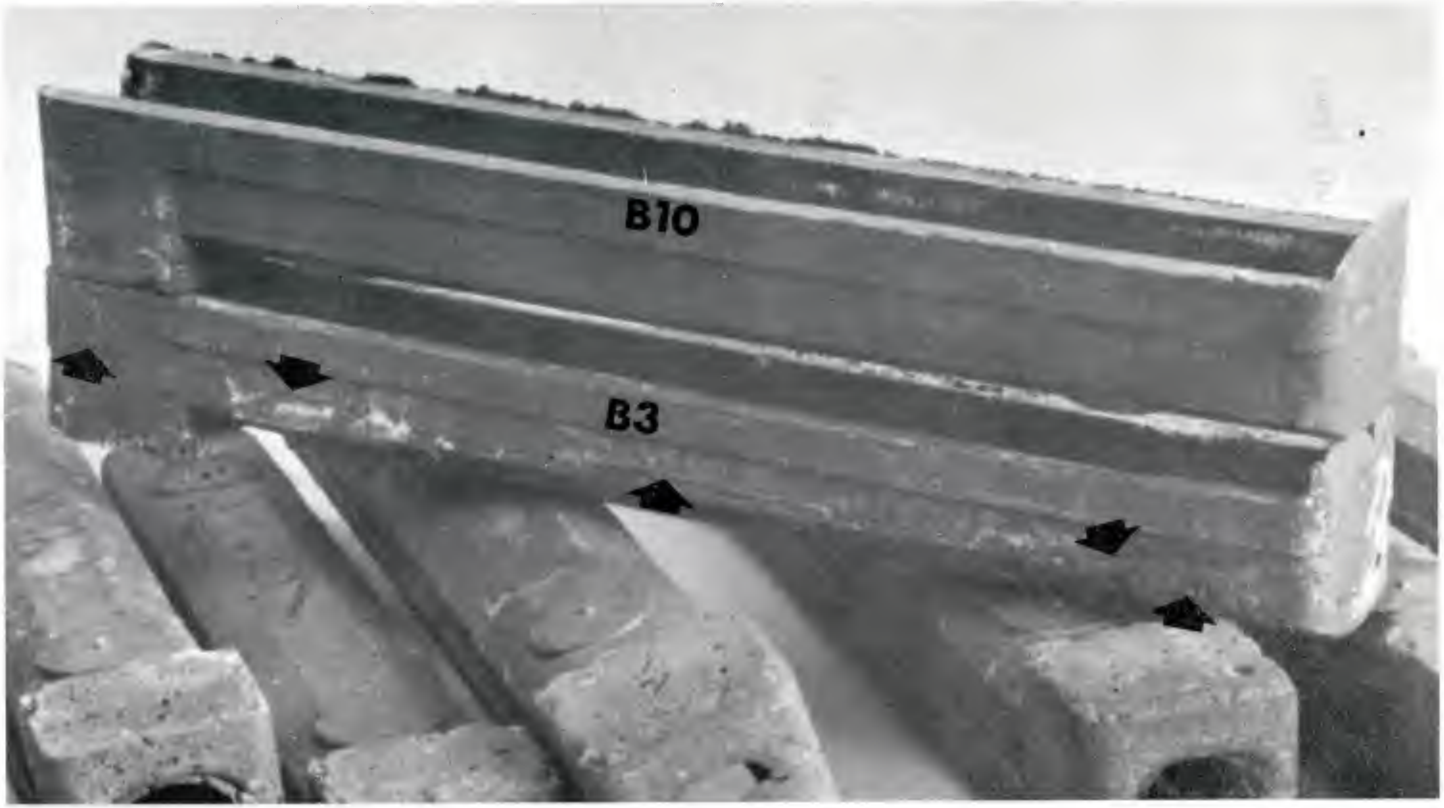
Several different criteria were employed to evaluate the quality of the squeeze castings. First, the surface appearance was inspected for finish and indications of any cracking or surface-connected gas holes. Dimensional measurements were carried out on a number of squeeze castings. Internal integrity of the castings was judged on the basis of radiography and, in a few cases, sectioning of the castings. Periodically, the composition of the material of the squeeze castings was checked. Different types of heat treating cycles were tried out to achieve the target tensile properties as measured on tensile specimens cut from the castings proper. The entire section refers to quality of the squeeze castings and die performance is referred to only to the extent that it affected the quality of the castings. Additional details about the die performance were presented in Section 5.

6.1 Surface Quality and Dimensional Inspection

Initial squeeze casting series with a new die set normally involves selection of proper melt volume and processing conditions and, as these conditions approach the optimum, dramatic improvement in the quality of the castings is achieved. Figure 28 illustrates the improvement in the surface appearance of casting B10 in relation to the casting B3.

For good mechanical properties, satisfactory appearance, and minimum machining, the surface of the squeeze castings must be free of porosity, cracks, and laps. Porosity is caused by gas generated from reactions between the molten metal and mold wash solids, mold wash vehicle, and the atmosphere. Cracks can occur if the squeeze casting is bent during ejection, if it is allowed to shrink on the die components, or if it is cooled too quickly and not uniformly from the squeeze casting temperature. Laps are caused by a layer of molten metal flowing against other portions of the melt which has already started to solidify.

The surface condition of the receiver base squeeze casting is predominantly affected by the temperature of the metal when first entering the die and when actually under pressure. As shown in Fig. 29, the holes and laps on the outside surfaces were minimized by increasing the temperature of the metal when actually under pressure. Although increasing the melt temperature from 2950° to 3050°F helped, the biggest improvement came from increasing the press closing speed from 40 to 600 ipm. This radically reduced the delay between pouring and die closure so that the work material temperature was much higher at the instant of pressure application.



Neg. No. 40384

Figure 28

Side View of Receiver Base Squeeze Castings B3 (bottom) and B10 (top) Showing Significant Improvements Made in Surface Finish in Few Runs. (Arrows show areas of defects.)

(a) B11 (2950°F, 40 ipm)

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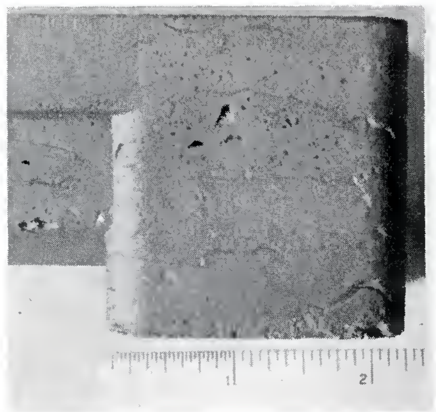


(b) B12 (2950°F, 60 ipm)

Neg. No. 40194

(c) B14 (3050°F, 600 ipm)

Neg. No. 40195

Figure 29

Effect of Melt Temperature and Press Speed in Minimizing the Occurrence of Holes or Laps on the Outside Surfaces of Receiver Base Squeeze Castings.

The metal contacted by the punch is the hottest because it is least influenced by the chilling effects of the bottom die walls. This contributed greatly to the good surface finish often provided by the Anviloy punch. In localized areas the surface finish was extremely good, as shown in Fig. 30. Although the surface was locally good enough to suit the net surface requirements, other areas often had surface depressions formed by lumps which developed on the surface of the Anviloy punch inserts. Other surface irregularities also occurred.

Cracks were detected on some initial squeeze castings on the surface formed by the Anviloy punch. These castings had been made with a 10 sec application of pressure, followed by immediately opening the die, then cooling of the squeeze casting, more often with the aid of a blast of compressed air. Increasing the load duration, leaving the dies closed after relaxation of load, then letting the squeeze casting slowly cool in the die to a low red heat without the aid of an air blast minimized the development of cracks. Figure 31 shows three receiver base squeeze castings which were sectioned, sandblasted, and then treated with a dye penetrant to illustrate the improved squeeze casting technique.

The second series of squeeze castings (Table 4) was made with a water-cooled die steel punch. Some of the squeeze castings made in this series showed some superficial cracking on the shoulder that is formed in contact with the punch. This occurred apparently because the new die steel punch was heated to a much lower temperature in relation to the 600° and 700°F used for the Anviloy punch. In any case, the cracks are fairly shallow in depth and would machine off easily. They can also be eliminated or minimized by heating the punch to a somewhat higher temperature.

The surface of the squeeze casting is more or less a reproduction of the die surface apart from the modifications made by the mold wash. In this series, an alumina-base mold wash, sprayed in the deep end of the bottom die where the incoming metal stream impinges, was followed by carbon soot, formed with an oxyacetylene torch, which was then applied over all the die surfaces. The surface of the squeeze casting formed by the die where only soot was applied was therefore an excellent reproduction of the die surface. Figure 32 shows the variation in the surface of the squeeze casting from the beginning to the end of the series. The surface shown is that formed by the new die steel punch on the interior of the channel-like receiver base. The coarsening of the punch evidenced by these photographs took place in about 50 squeeze castings. A machining allowance is provided on this squeeze casting so that the surface finish will not cause any

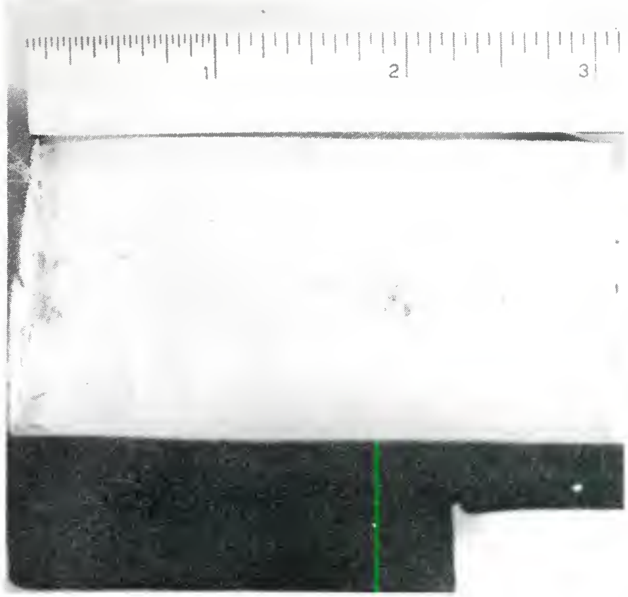
Neg. No. 40383

Figure 30

Surface Finish Produced by Anviloy Punch Inserts.
(Receiver Base B34)
(Arrows indicate the excellent finish
on the inside surface.)

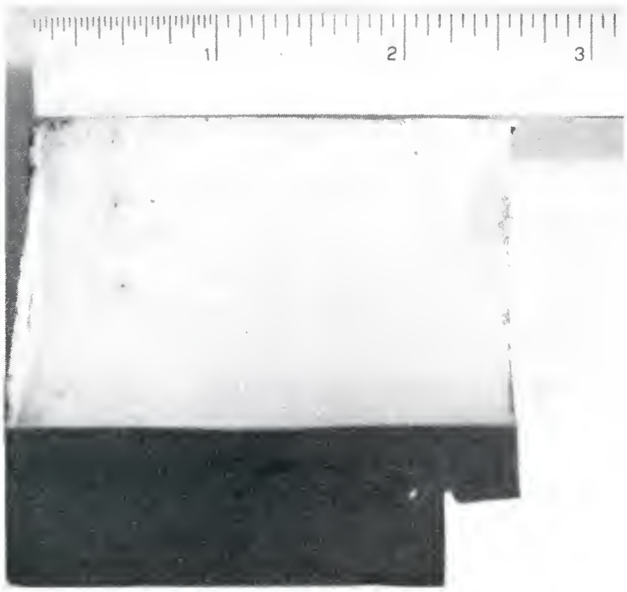
Neg. No. 40197

(a) B17, 220 tons for 10 sec



Neg. No. 40199

(b) B18, 220 tons for 30 sec



Neg. No. 40198

(c) B20, 220 tons for 30 sec. Cool in die for 30 sec (dies closed), cool in die for 120 sec (dies open).

Figure 31

Effect of Load Duration and Slow Cooling in Minimizing Cracks on the Inside Surfaces of the Receiver Base Squeeze Castings.

(a)
Squeeze Casting B79

(b)
Squeeze Casting B124

Figure 32

Variation in the Surface Appearance of the Squeeze Casting as an Indication of the Punch Surface Appearance problem in terms of machining satisfactory components from the squeeze castings. Although the punch showed this coarsening and suffered some minor deformation towards the ends of the squeeze casting, it was still capable of producing good quality squeeze castings. However, the punch did need some occasional maintenance, and it would be desirable from a production standpoint to utilize a better die material such as Inconel 718 which has proved to be so satisfactory as a punch material for the barrel support die set.

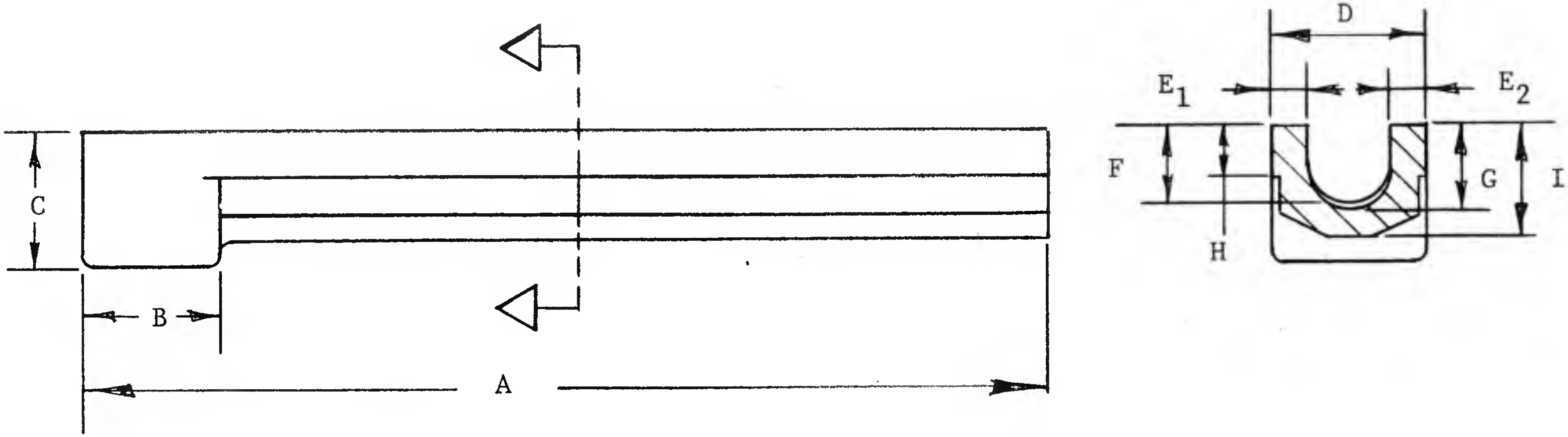
Thirty-three receiver base squeeze castings were selected on the basis of surface quality from the second series and were subjected to extensive dimensional evaluation as illustrated in Fig. 33. This consisted of taking ten measurements per squeeze casting and comparing them to the finish-machined drawing in order to determine if there is adequate machining allowance. The average dimensions are given in Fig. 33 along with the tolerance bands for each location in order to give an indication of reproducibility. Dimensions C, H, and I are affected by the casting weight; they are analogous to dimensions affected by die closure in conventional forgings and show wider variation than the others. The tolerance bands for the other eight dimensions are comparable to those for conventional forgings. The evaluation showed that all 33 pieces had adequate material for final machining. After closer inspection of the surface quality, 20 pieces were selected as best quality and were submitted to the Army for further extensive evaluation. Subsequently, more squeeze castings were made in the second series, and 15 more were submitted to the Army.

6.2 Internal Integrity

The quality of the receiver base squeeze castings was investigated by cutting, polishing, and etching several sections and by radiography. The investigation indicated in general a fine grain structure but, in a few cases, shrinkage porosity was noticed. This was, however, completely eliminated through die modification and usage of auxiliary cylinders as discussed later.

In any casting process, the solidification occurs at different rates depending on the section thickness. A section that remains molten much longer than the rest of the squeeze casting would receive little effective pressure during solidification and shrinkage cavities would result.

In the receiver base, much of the length has a uniform cross-section but, at one end, a small portion has much heavier thickness. In this region, in the first series some



A	B	C	D	E_1	E_2	F	G	H	I	Remarks
$17\frac{17}{32}$	2.551	2.335	2.531	0.529	0.527	1.508	1.552	0.913	1.912	Squeeze casting dimension (avg. of 33)
$+\frac{1}{32}$	+.030 -.040	+.050 -.115	+.020 -.020	+.002 -.003	+.004 -.002	+.015 -.020	+.020 -.010	+.065 -.120	+.045 -.060	Tolerance band
17.068	2.12	2.145	2.377	0.415	0.415	1.521	1.571	0.510	1.70	Dimension of machined part
+.000 -.010	±.03	±.010	+.000 -.002	+.000 -.005	+.000 -.005	+.000 -.005	+.010 -.000	+.000 -.012	+.00 -.01	Tolerance band

Figure 33

Dimensional Inspection of Receiver Base Squeeze Castings
(All dimensions in inches)

heavy porosity occurred. The porosity was minimized early in the series by using a high load and maintaining it for 30 sec. Sections of castings B18 and B20 are shown in Fig. 34 illustrating the results of this technique. After squeeze casting B21, the die was modified by extending the length of the cavity at the heavy end by 1/4 in. (see Section 5.1.2). The heavy local porosity continued to occur occasionally, Fig. 35,* and the minor die modification did not seem to have any influence on it.

The local shrinkage porosity is caused by various factors such as flash thickness which increases as the die wears, inconsistent press speed due to ram overheating, and any die deformation. Such factors make it difficult to transmit the pressure during the final stages of solidification in the heavy sections. The effect of heavy loads maintained for longer time periods is not consistent enough because of the interference of these factors. It was for this reason that the die modification described in Section 5.2.2 was incorporated at the end of the second series to provide two auxiliary hydraulic cylinders. Also, the cracked Anviloy punch was replaced by a new water-cooled H13 die steel punch.

An important objective of the second series was to eliminate the porosity in the heavy end of the squeeze casting. A number of squeeze castings made with the auxiliary pressure were subjected to radiographic examination on the thick end section. As shown in Fig. 36, the radiographs were clear, demonstrating that the castings were free of any porosity like that noticed in the first series. Several squeeze castings were sectioned to confirm that there was indeed no porosity at the thick end.

Cross-sections of a squeeze casting and a sand casting are shown in Fig. 37. There is some very fine porosity on the centerline of the squeeze casting, whereas the sand casting shows much more porosity distributed throughout the cross-section. The fine porosity in the squeeze casting is considered to be within the acceptable limits. In any case, the squeeze casting shown here was produced with a relatively low pressure of only 10,000 psi; if necessary to minimize the porosity further, somewhat higher pressures can be utilized.

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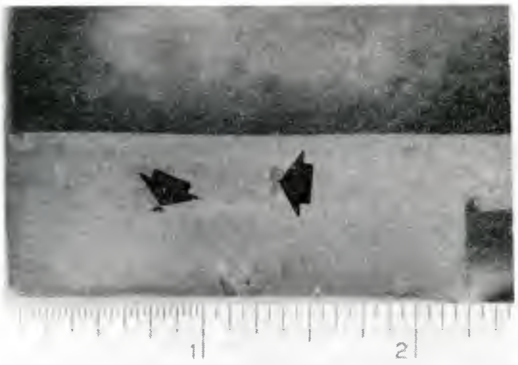
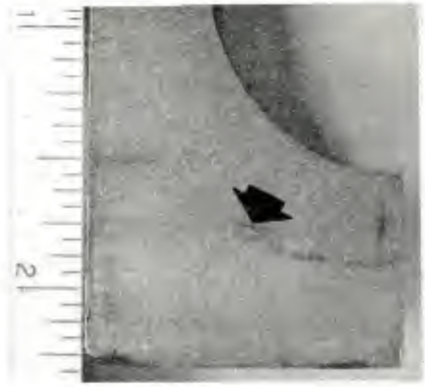
*Prints from radiographs are shown in this and subsequent figures. Note that porosity appears lighter than sound portions.





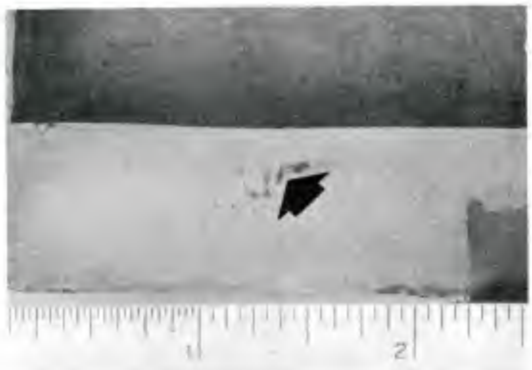
Neg. No. 40190

Section A-A

Neg. No. 40191

Section B-B

(a) B18, 220 tons for 30 sec



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Section A-A

Neg. No. 40193

Section B-B

(b) B20, 220 tons for 30 sec

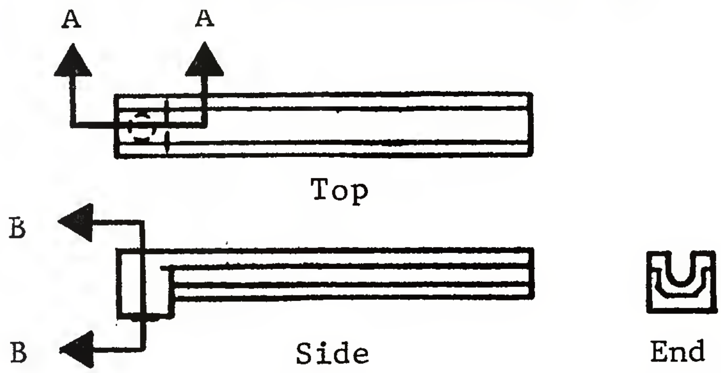


Figure 34. Effect of High Loads Maintained for Several Seconds in Minimizing Porosity in the Thick Sections of the Receiver Base (arrows indicate porosity).

Etchant: 50% HCl + 50% H_2O (hot).

(a) B21

(b) B33

(c) B45

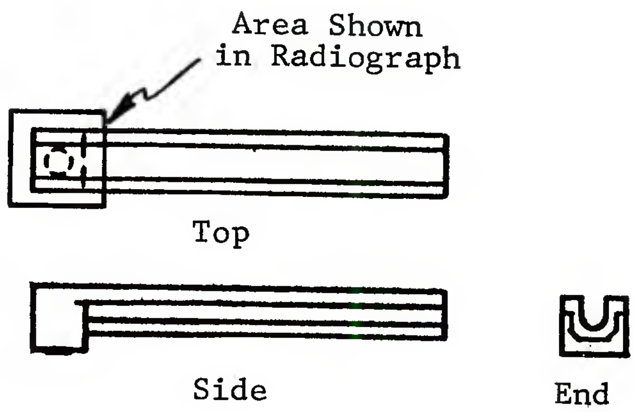
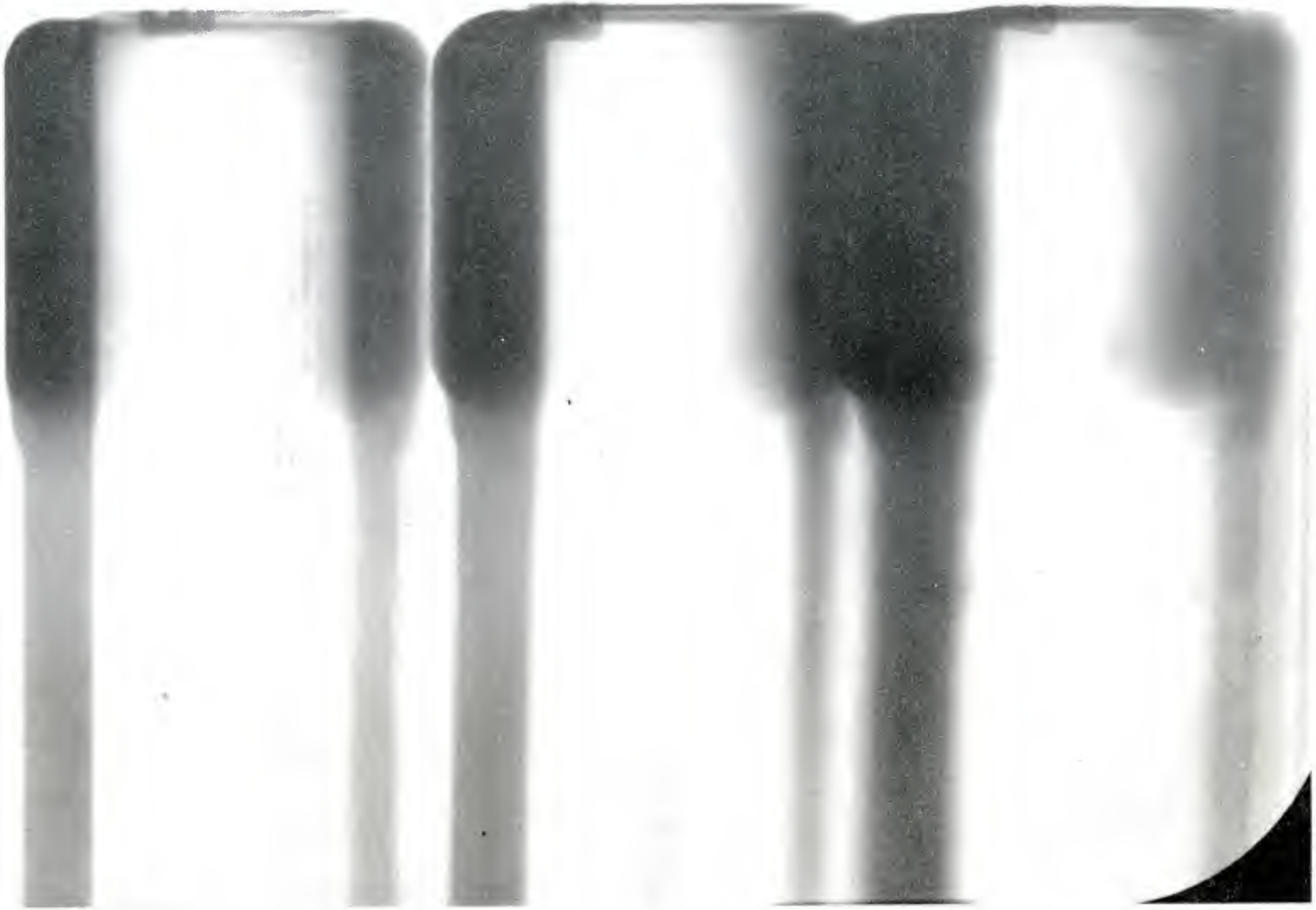


Figure 35

Prints from Radiographs of the Thick End of Receiver Base Squeeze Castings. (Porosity indicated by arrows.)



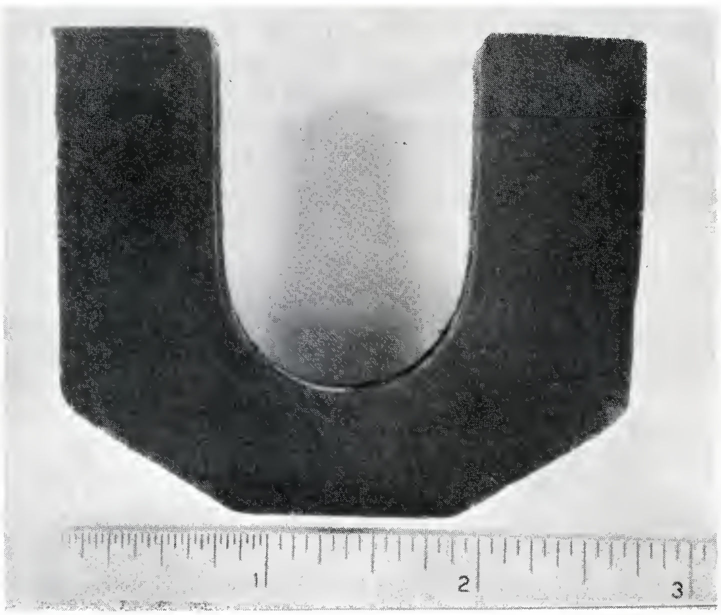
(a) Squeeze Casting B81 (b) Squeeze Casting B80 (c) Squeeze Casting B79

Figure 36

Print from Radiograph Showing Excellent Quality of the Receiver Base Castings Made with Auxiliary Pressure

Neg. No. 41406

(a) Squeeze casting



Neg. No. 41407

(b) Sand casting

Figure 37

Comparison of the Cross-Section of a Squeeze Casting and a Sand Casting

6.3 Heat Treatment, Mechanical Properties, and Composition

The receiver base sand castings are currently made according to specification QQ-S-681 which corresponds to 140,000 psi tensile strength, 115,000 psi yield stress, 10% elongation, and 25% reduction in area. In the case of sand castings, these properties are normally checked on keel blocks cast separately from the casting of the component proper. Because of the large size and a relatively large riser, keel block casting is generally of very high integrity and soundness and is large enough to allow making test samples of standard dimensions. This technique was not used in the subject program and all the following comments refer to tensile test specimens cut directly from the squeeze castings and not from an independently made keel block.

Proper control over composition of the material is essential for obtaining the desired properties. As discussed in Section 4.3, the composition was controlled by additions for carbon, manganese, and molybdenum. The proper level for such additions was decided on the basis of the melt weight to be used, the composition of the melt stock, and checks on composition of the castings made in the first few trials. Periodically the composition was checked on drillings from a few castings. The analysis obtained in such tests are given in Table 9. The aim composition was that found in a typical sand casting since it was known to lead to the desired properties as checked on the keel block casting. Because of the standardized experimental procedure, no difficulty was encountered in achieving the proper composition. The only exceptions were in the case of phosphorus and sulfur where the as-received melt stock had more proportion of these elements than in a typical sand casting and, consequently, the squeeze casting also has higher phosphorus and sulfur content.

In order to determine the proper heat treatment, quenching and tempering tests were conducted. The long trough-like portion of the B20 receiver base was cut in half. Both pieces were then austenitized at 1570°F in an argon atmosphere. One section was water quenched and the other oil quenched to determine how fast a quench would be required. Hardness readings in the range of R_C 40-44 were taken from the outside surface of the water-quenched piece after local grinding to remove any decarburized layer. Apparently the low carbon content of the B20 squeeze casting made it unsuitable for oil quenching. Therefore, additional testing was performed with the water-quenched section of B20.

Table 9

ANALYSIS OF COMPOSITION OF RECEIVER BASE SQUEEZE CASTINGS

Exp. No.	Composition, %							
	C	Mn	Si	P	S	Ni	Cr	Mo
B10	.27	.74	.64	-	-	.43	.36	.19
14	.21	.52	.40	-	-	.50	.50	.19
20	.20	.65	.41	.020	.024	.50	.49	.36
23	.26	.67	-	-	-	.50	.48	.49
Typ. Sand Casting at RIA	.25	.75	.50	<.010	<.010	.50	.55	.55

A 0.5 in. thick slice was carefully removed with a water-cooled cutoff wheel in order to avoid tempering during cutting. Hardness readings taken on this slice showed an average reading of R_C 42 throughout the section. This slice was then cut with the water-cooled cutoff wheel in three pieces for tempering tests.

Each of the three pieces were tempered at different temperatures for 1 hr. The average hardness of these pieces was R_C 37, R_C 37, and R_C 27 for tempering temperatures of 900°, 1000°, and 1100°F, respectively. An approximate correlation of tensile strength to Rockwell hardness suggested R_C 30 as the minimum desired metal hardness. Interpolation gave 1070°F as the preferred tempering temperature, and therefore the remaining portion of the water-cooled section was tempered for 1 hr at 1070°F.

Three tensile specimens were machined from the water quenched and tempered sections of B20. These tensile specimens were of an ASTM subsize rectangular type having a typical gage dimension of 0.25 in. wide by 0.25 in. thick with a 1.0 in. gage length, and were tested at room temperature at 0.05 ipm. The tensile data are summarized in Table 10.

Two of the three tensile specimens from the receiver base gave satisfactory properties. The third, however, had unusually low elongation and reduction of area even though the hardness was relatively low (R_C 30). This suggested that there might have been a flaw in the gage area, but inspection of the specimen after testing revealed no obvious defects.

As mentioned above, the castings are generally evaluated in terms of properties of a keel block cast separately instead of on the basis of tensile test data from samples cut from the casting proper. Since the keel block type of approach was not used with the squeeze castings, some data were obtained by Rock Island Arsenal by cutting samples from sand castings. The data obtained along with the keel block data are shown in Table 11. Similar data obtained from the samples cut from receiver base squeeze casting B84 are also shown in the table.

A 6-in. section was cut from the thin end of B84. This piece was then normalized, austenitized, and water quenched. A final hardness in the range of R_C 32-33 was desired in order to produce the required mechanical properties. The quenched piece was tempered for 1 hr at 1050°F and cut into two pieces for finish machining into tensile specimens. The average hardness of these pieces was R_C 36 and, therefore, they needed additional tempering. Tempering at 1110°F for 1 hr resulted in an average hardness of R_C 34 for the two pieces. Tempering for an additional hour at 1150°F gave the desired average hardness of R_C 33.

Table 10

TENSILE PROPERTIES OF RECEIVER BASE SQUEEZE CASTINGS

(1.0 in. gauge length, 0.25 x 0.25 in. gauge area, 0.05 ipm crosshead speed)

Identification	Treatment	Hardness (avg) R_C	YS (0.2% offset), psi	UTS, psi	Elong., %	Reduction of Area, %
Desired Properties	-	-	115,000	140,000	10	25
B20	a,b	32	135,000	143,500	15	34
	a,b	31	129,500	139,000	17	40
	a,b	30	124,500	134,500	10	18

[a]Austenitized at 1570°F and water quenched.

[b]Tempered at 1070°F for 1 hr.

Table 11

COMPARISON OF TENSILE PROPERTIES OF RECEIVER BASE SAND CASTINGS AND SQUEEZE CASTINGS

Identification	Test Bar Location (see Fig.)	Treatment	Hardness (avg) BHN	Hardness (avg) R_C	YS (0.2% offset), psi	UTS, psi	Elongation, %	Reduction of Area, %
Aim Properties	--	--	--	--	115,000	140,000	10	25
Keel Block[a]	--	b	341	37	147,000	164,000	11.8	39.7
Sand Casting[a]	A	b	341	37	150,500	164,000	10.0	25.7
Sand Casting[a]	A	b	341	37	154,500	165,500	9.6	25.3
Sand Casting[c]	B	b	341	37	150,500	154,500	2.9	9.4
Squeeze Casting[d] B84	A	e	319	34	131,500[f]	138,500	13	26
Squeeze Casting[d] B84	A	e	311	33	131,000[f]	138,000	14	29

[a] 0.505 gage diameter, 2.0 gage length.

[b] Normalized at 1700°F, austenitized at 1625°F, water quenched. Tempered: 2.5 hr at 1025°F, 1.0 hr at 1050°F, 1.0 hr at 1100°F.

[c] 0.375 gage diameter, 1.4 gage length.

[d] 0.25 x 0.25 gage area, 1.0 gage length, 0.05 ipm crosshead speed.

[e] Normalized at 1700°F, austenitized at 1620°F, water quenched. Tempered: 1.0 hr at 1050°F, 1.0 hr at 1110°F, 1.0 hr at 1150°F.

[f] 0.2% offset not required because of "sharp kneed" stress-strain diagram.

Test Bar Location in Castings

Two tensile specimens were machined from the heat treated sections of B84. These tensile specimens were of an ASTM sub-size rectangular type having a typical gage dimension of 0.25 in. thick with a 1.0 in. gage length, and were tested at room temperature at 0.05 ipm crosshead speed.

The squeeze-cast tensile properties (Table 11) were very good with yield strength, elongation, and reduction of area exceeding the desired properties. However, the ultimate tensile strength was slightly low. A slightly higher hardness could produce the desired ultimate tensile strength with a small, but acceptable, reduction in ductility.

The squeeze castings have fine columnar grains growing from each surface. It was felt that by normalizing prior to any other heat treatment the structure could be made more uniform and this might enhance the ductility. Therefore, a number of tests were conducted with six samples, two of each normalized at 1700°, 1950°, and 2200°F. All the six samples were then austenitized for 20 min at 1150°F, water quenched, and tempered at 1120°F. The resulting tensile test data are shown in Table 12. The ductility data are adversely affected because of some flaw in the casting, but it can be seen that the high normalizing temperature has the effect of making the yield stress and ultimate strength values more reproducible. Consequently, in a production facility, normalizing will be a valuable first step prior to heat treatment. This is already done in the case of the sand castings and does not pose any restrictive requirements.

The tensile tests have shown that the squeeze castings will have no problem meeting the yield stress and ultimate strength requirements and, very likely, the ductility. In some cases, the ductility is somewhat low because of obvious defects in castings. This may be because the squeeze castings were made by melting the material individually thus making the control over melt quality more difficult. In production, when the material is molten in large quantities, significant improvement in melt quality should result. It is also possible that the low ductility in a few cases points to the need for additional work on optimization of material composition and heat treatment. The ductility is also affected by the subsize specimens necessary because of the thinness of the squeeze castings. It is well known that elongation is very sensitive to the specimen size and smaller specimens show apparent lower elongation values, Fig. 38. Another contributory factor may be that the squeeze castings were made with parallel walls without any draft on the vertical die walls, and this may have caused some fine centerline porosity which could be eliminated readily by provision of

Table 12

TENSILE PROPERTY DATA FOR RECEIVER BASE SQUEEZE CASTING
WITH DIFFERENT NORMALIZING TEMPERATURES

Normalizing Temperature, °F	Hardness, R_C	YS (0.2% Offset), psi	UTS, psi	Elong., %	Reduction of Area, %
1950	33.0	138,470	144,900	6	16
1950	34.5	137,940	140,490	4	8
1700	33.0	130,440	136,680	6	14
1700	34.0	138,410	145,480	6	18
2200	31.0	127,260	137,170	6	16
2200	34.5	127,720	136,410	6	9

Notes:

1. Heat Treatment:

   Normalized at temperatures listed for 2 hr. Austenitized at 1550°F for 20 min and water quenched. Tempered at 1120°F for 1 hr.

2. Sections cut from receiver base casting B171 and then heat treated.

3. Gage length 1.4 in., diameter 0.35 in.

4. In all samples, the ductility was adversely affected by a flaw observed after testing.

5. The desired properties were 115,000 psi YS (0.2% offset), 140,000 psi UTS, 10% elongation, and 25% reduction of area.

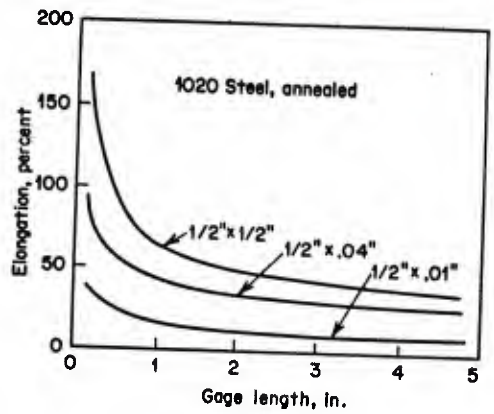


Figure 38

Effect of Gage Length and Cross-Sectional Area on Elongation Values Recorded in Tensile Testing(26)

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(26) E. B. Kula and N. H. Fahey, in Proc. 7th Sagamore Conf., New York, 1960

draft on the punch and die walls. In conclusion, it is reasonable to expect that in a production run the squeeze castings would consistently meet the required tensile property specifications.

6.4 Potential for Cost Reduction

The cost reduction potential of the receiver base squeeze castings is indicated in three areas of work material, finish machining, and processing.

The squeeze casting process does not require any risers or gates and, consequently, the material yield from the poured weight to the casting is of the order of 90%. In addition, the total weight of the casting is only 12 to 13 lb instead of the sand casting weight of 47 lb with risers and gates. This large difference in material weight should result in some saving since even when the scrap is remelted in the sand casting operation, there are invariably some losses and some expenses are also incurred in remelting and handling the larger amount of material.

The major cost saving offered by the squeeze casting technique results from the substantially lower processing costs in comparison to the sand castings. The molds for sand casting must be individually made; then the casting must be removed by breaking off the mold; and finally, the risers and gates must be trimmed from the casting. All of these, and especially the latter two, involve a significant amount of manual operations particularly since the receiver bases are not required in large quantities. In comparison, squeeze casting eliminates all of these operations and only minor die rework is required. Furthermore, a sand casting foundry must store the large patterns and huge quantities of molding sand, and must also provide machines and labor for much material handling and trimming. The squeeze casting process will greatly reduce the requirement for labor and space and, to a large extent, for equipment.

The cost of a casting is affected significantly by the equipment cost and the rate of production. In relation to sand casting, the production rate in squeeze casting is likely to be substantially higher. The duration of pressure in squeeze casting is of the order of only a few seconds in which the solidification is completed because of the high pressure and the resulting better thermal contact and rapid rate of heat transfer from the casting to the dies. The rate of production in a production facility is, therefore, likely to be controlled almost entirely by the material handling capability associated with the main squeeze casting equipment.

Even with a single squeeze casting machine, with proper handling and manipulating equipment, the production rate could be as high as 1 to 2 parts per minute or 60 to 120 parts per hour. Multiple machines or usage of multiple station facilities can boost up the production rate even higher. This higher rate will reflect directly in lower unit cost.

Because of the high quality requirements on the receiver base and the barrel support, these components are subjected to 100% radiographic inspection. Basically, the same type of inspection will be required on the squeeze castings also. However, even here some reduction in inspection costs could result since the squeeze castings could be inspected more or less in the as-squeeze cast condition whereas the sand casting must often be partially machined after the trimming operation to facilitate inspection. Furthermore, once a squeeze casting facility is fully operational and the processing is optimized, the rejection rate is likely to be much lower than the current rate for the sand casting.

For a given production rate capability, the overall investment is also likely to be lower with the squeeze casting process since, for producing the same number of parts in the same given time, the melting and melt handling equipment required for squeeze casting will be much lower in capacity than for sand casting. This, plus the reduced need for auxiliary equipment for cleaning and trimming, may more than offset the cost required for the squeeze casting press. It is expected that the per-unit cost of a squeeze casting will be substantially lower than the per-unit cost of a trimmed sand casting.

The finish machined weight of the receiver base is only 6.2 lb. The squeeze casting weighs 12 to 13 lb whereas the trimmed sand casting, excluding risers and gates, weighs 21 lb. Thus, the squeeze casting will require substantially less machining than sand casting and should show lower machining costs. Of course, much of the machining cost is in the machining operations and, therefore, the actual saving in machining costs will not be as high as the differences in weights would suggest at first sight.

On the whole, the cost of the receiver bases in fully machined condition is likely to be substantially less when they are made from squeeze castings as against making them from conventional sand castings. Some of this cost reduction is likely to be due to the reduced cost of the material and the lower rejection rate with the squeeze casting process. But the bulk of the reduction in cost could result from the lower processing costs with the squeeze casting process.

Finally, it must be mentioned that if a sudden increase in the production rate is required, the squeeze casting process is amenable for such quick change far more easily than sand casting, and this could lead to substantial savings in cost as well.

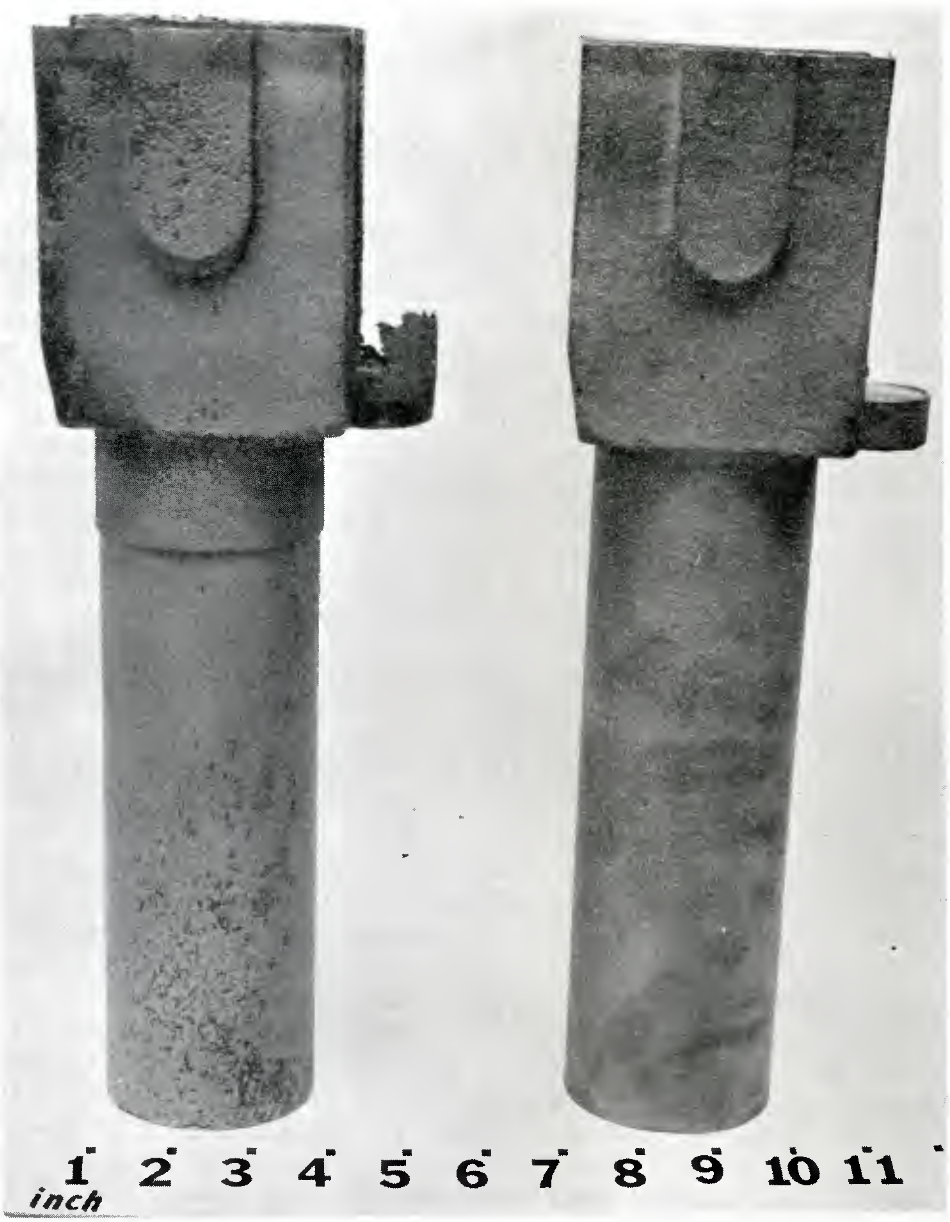
7. PARAMETRIC STUDY AND EVALUATION OF BARREL SUPPORT SQUEEZE CASTINGS

In this section, the evaluation of the squeeze castings is discussed along the same lines as in Section 6 for the receiver base. This includes surface quality, dimensional inspection, internal structure, material composition, heat treatment, and mechanical properties. Additionally, experiments were carried out with different punch materials to compare their performance and suitability for the squeeze casting process. Also, the punch length was varied and this, coupled with the various die modifications, made it possible to study the effect of component geometry on the quality of the squeeze castings. Finally, some of the key process variables such as load, duration of load, and melt temperature were varied to study how such process parameters influence the squeeze casting quality.

7.1 Surface Quality and Dimensional Inspection

In the squeeze casting process, as soon as the melt is introduced into the lower die, it begins to solidify where it comes in contact with the die. Then on closing the die, the punch displaces the material and the die cavity is filled. Consequently, the squeeze castings which had, on the whole, excellent surface appearance had a particularly good finish in the upper portions of the casting. The difference in finish on different portions of the casting was more obvious with a lower than optimum melt temperature. As expected, the best surface finish was produced on parts which were made with a fast press speed and high pouring temperature. The inside surface of the tube portion was coarser in the first series than the outside because of the coarseness of the glass coating and the mold wash applied to the punch. In subsequent series, a thinner and more uniform glass coating was given to the punch at the start of the series and resulted in a substantial improvement of the finish on the interior of the tube-like portion.

With the proper selection of processing conditions, the surface finish on the squeeze casting depends mainly on the condition of the die cavity surfaces. As the ceramic mold wash built up on the dies, there was some noticeable deterioration of the finish in the squeeze casting through No. A58. In the subsequent trials with carbon soot as the mold wash, the buildup of the ceramic material was gradually removed and this led to an improvement in the surface finish. A comparison of the surface finish of the castings with ceramic mold wash and with carbon soot is shown in Fig. 39. In fact, such a significant improvement in the surface finish was



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(a) A36 (b) A63

Figure 39

Surface Appearance of Barrel Support Squeeze Castings
(a) Made with Alumina Mold Wash
and (b) Made with Carbon Soot

achieved that towards the end of the program, the finish obtained on the squeeze castings was far superior to that of sand castings and hot forgings and approached that commonly obtained in cold forgings. Figure 40 shows an example of the finish of a squeeze casting exactly as it was removed from the dies and without any cleaning or treatment of the surface.

The barrel support squeeze castings showed two types of cracks. The more severe type of cracking was in the tube-like section and was a direct result of the limitations of the available hydraulic press. As discussed in Section 5, because of the low retraction force available on the press, in many cases the dies could not be opened immediately at the completion of the squeeze casting operation as was desired. Consequently, the squeeze castings shrunk around the metallic punch and suffered hot tearing. The cracks were normally longitudinal and extended for 3 or 4 in. over the tube-like portion. Such cracking was aggravated by the thin wall and long length of the squeeze casting. The effect of such geometric parameters is discussed in Section 7.5, and one way of eliminating the cracking is suggested. In any case, with a press specially designed for the process, this type of cracking can be easily eliminated.

In some squeeze castings made in Series 1 and 2, cracking was observed at the corners at the intersection of the tubular and the rectangular portions of the barrel support, Fig. 41. This cracking was a direct result of the sharp corner radii in this section. The sharp radii were initially used in an effort to make the interior part of the squeeze casting net to finished dimensions. After the second series, the dies were modified to give generous radii to the punch support that forms this portion and the modification completely eliminated the particular type of cracking. Consequently, a number of squeeze castings were produced which were completely free of any cracks of either of these two types.

Dimensions were measured on several squeeze castings made in the first two series to obtain an idea about the dimensional precision of the squeeze castings as well as to determine if the dimensions are adequate for finish machining of the components. The data are presented in Fig. 42. Eight different squeeze castings were measured, and the ranges provided for each dimension give some idea of its reproducibility. Dimensions B and C are affected by the casting weight and are analogous to dimensions affected by die closure in conventional forgings. They show somewhat wider variations. The tolerance bands for other dimensions are comparable to those for conventional forgings. Because

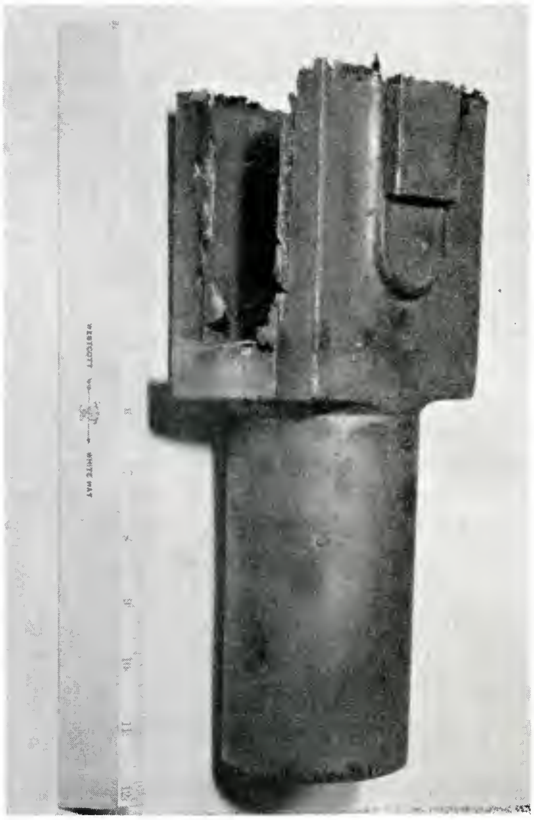

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Figure 40

An Example of the Excellent Surface Appearance
of Barrel Support Squeeze Castings
(shown as-cast, without any cleaning
or surface preparation).

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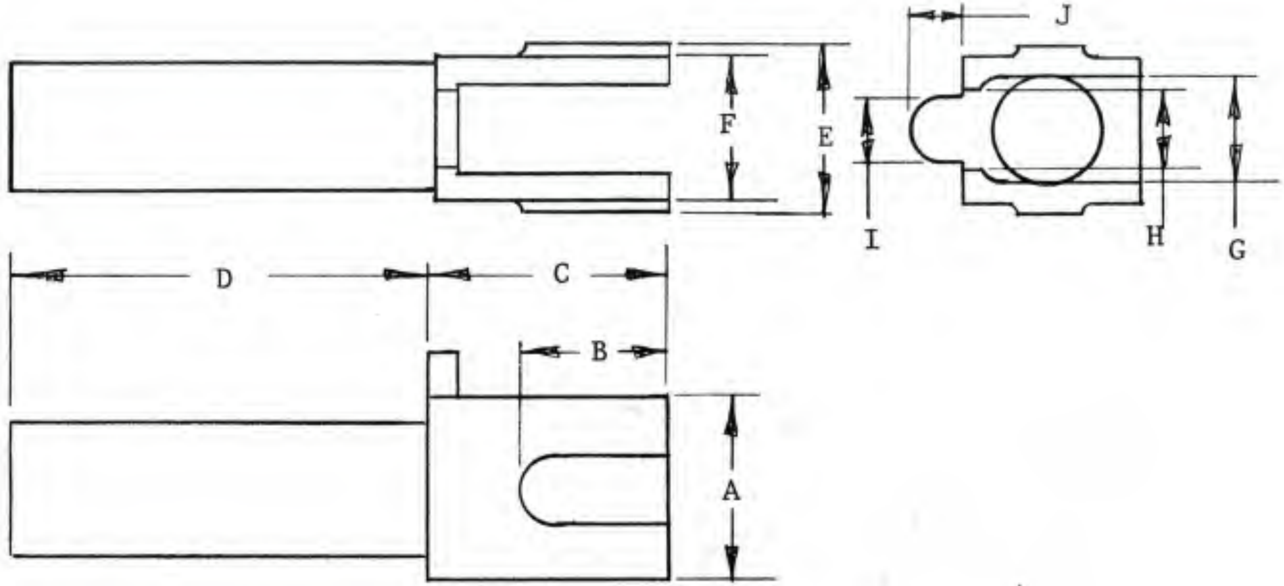
Figure 41

Cracks Found in Inside Corners of Some
Barrel Support Squeeze Castings
(A35 shown)



Description	A	B*†	C*	D	E	F	G	H	I	J
Avg of 8 squeeze castings	3.783 -.018 +.024	2.64 -.04 +.11	4.73 -.04 +.12	9.22 -.04 +.04	3.605 -.020 +.009	3.239 -.014 +.014	2.484 -.010 +.008	2.367 -.010 +.010	1.502 -.012 +.016	1.05 -.00 +.01
Design dimension for machined component	3.830 -.030	3.03 +.06 -.13	4.75	9.30 ±.03	3.63 -.01	3.255 -.010	2.556 +.030	2.376 +.003	1.52 -.02	1.055 -.020

*Dimensions affected by squeeze casting weight.

†Large difference in as-cast and as-machined dimensions is due to error in die drawing.

Figure 42

Summary of Dimensional Inspection of Barrel Support Squeeze Castings

(All dimensions in inches)

of the difficulty of predicting a priori the differences in die and casting dimensions, some of the casting dimensions showed inadequate material for finish machining of the components. Dimension B was too low because of an error in the drawing. The die modifications discussed in Section 5.2.2 were arrived at in part on the basis of the inspection data in Fig. 42 and led to the proper dimensions on the squeeze castings made in the subsequent series.

7.2 Internal Integrity

The quality of the interior of the squeeze casting was inspected by radiography and by sectioning a number of squeeze castings. The tube-like portion of the barrel support was found to be sound except for some centerline shrinkage and subsurface inclusions found in the castings made in the first two series. The subsurface inclusions were eliminated when the mold wash was changed to carbon soot from a ceramic mold wash. The centerline shrinkage was very minor and was found only in a few cases when the punch was slightly eccentric causing the wall thickness on one side to be thicker than on the opposing side. The shrinkage occurred on the thicker side. After the second series a new Inconel 718 punch was made, and the concentricity was excellent and the centerline shrinkage was eliminated.

The rectangular portions of the barrel support and the interface between the rectangular portion and the tubular portion were also inspected for internal porosity. Examples of an excellent and a poor casting are shown in Figs. 43 and 44, respectively. In general, when the double-acting type of operation was not properly achieved, some porosity was also found on the interface, but otherwise the porosity, if present, occurred only in areas such as shown in Fig. 44. Attempts were made to correlate the porosity with the process parameters, and castings were made with melt temperature ranging from 2950° to 3100°F, load ranging from 150 to 200 tons, and with a 130°F difference in die temperatures. The press speed was also varied. Generally, it was very difficult to correlate the occurrence of porosity with the process parameters on the basis of a few available tests except that a press speed of greater than 300 ipm appeared to yield squeeze castings of better quality.

Good quality squeeze castings were also made in later series and an example is shown in Fig. 45. In the final series, when the dies were modified by increasing the corner radii to eliminate the cracking in the corner (see discussion above), it unfortunately also resulted in an increase in the

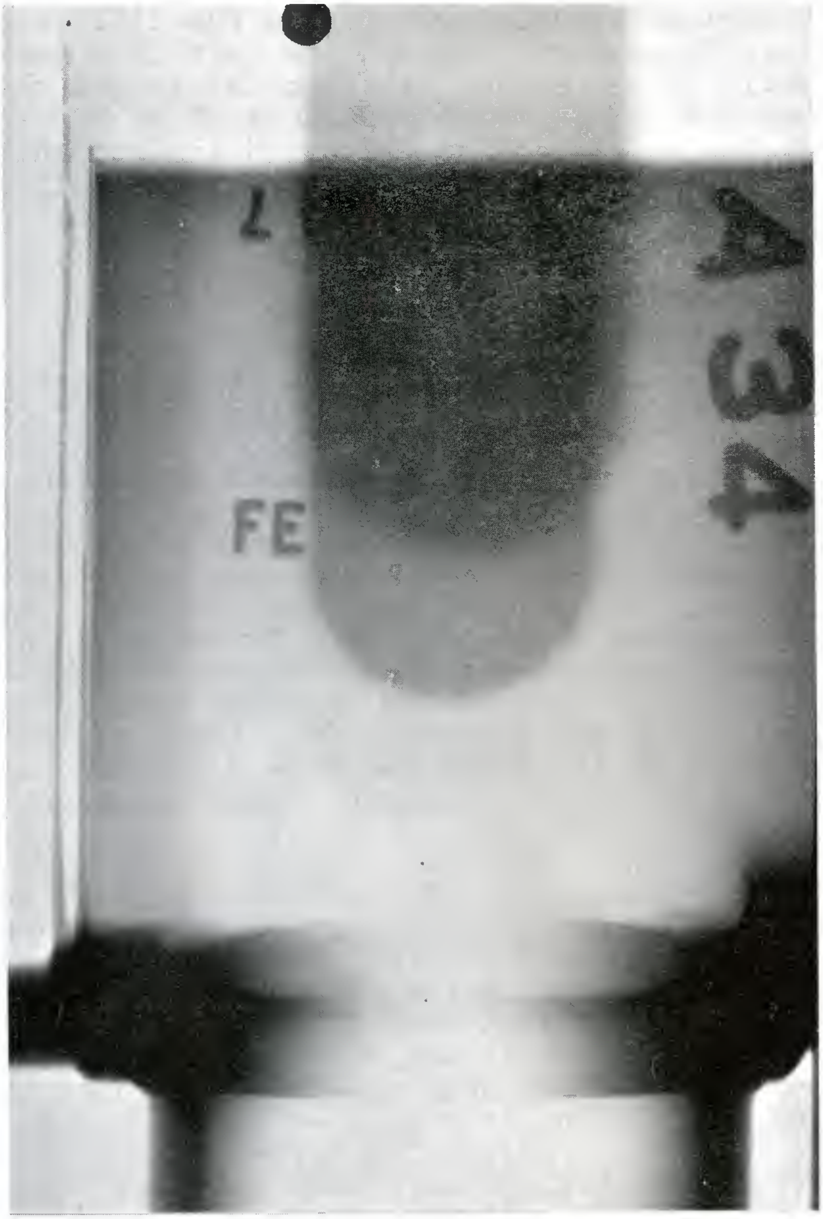


Figure 43

Print from Radiograph of Barrel Support A34 Made with a Melt Temperature of 3000°F, 200 Ton Load, 719°F Die Temperature, and Approximately 315 ipm Press Speed. (Note the absence of any porosity.)

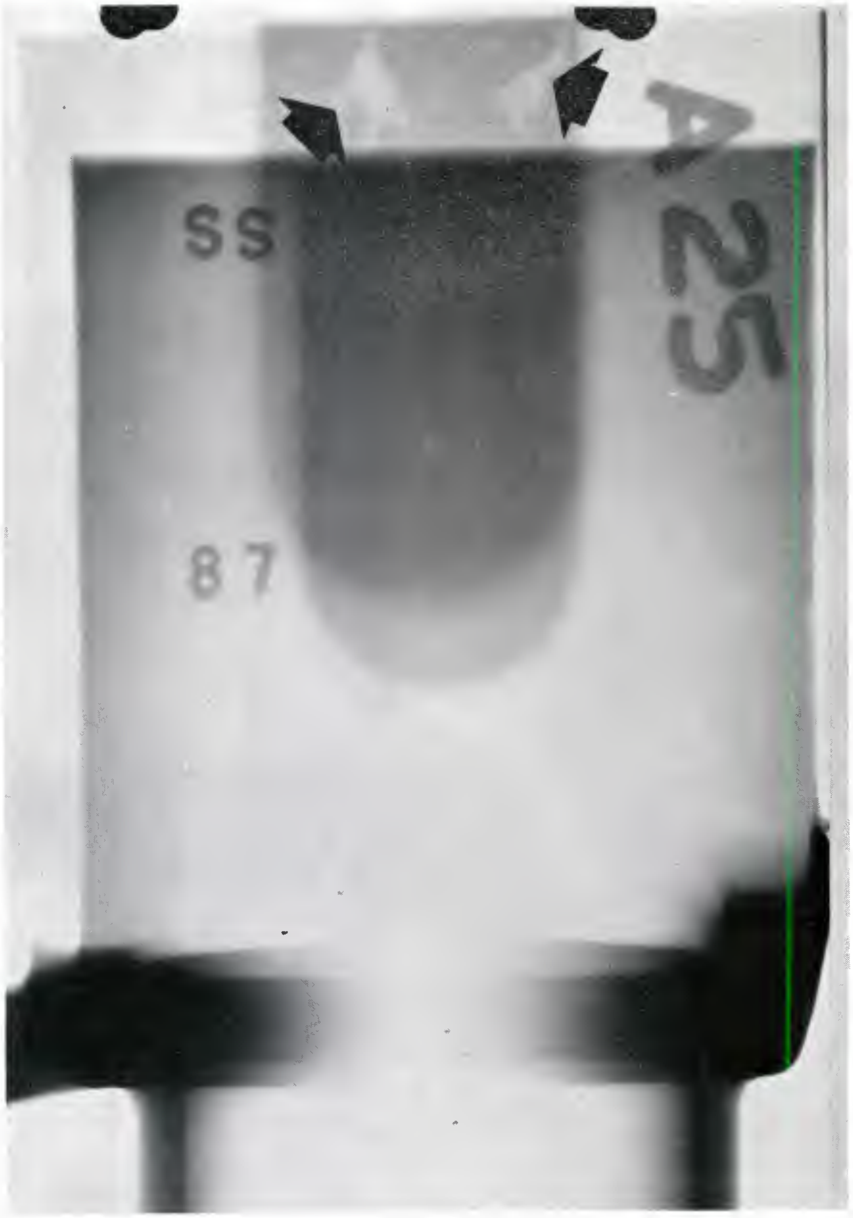


Figure 44

Print from Radiograph of Barrel Support A25 Made with a Double-Acting Die, Showing the Location of Porosity. (Porosity indicated by arrows.)

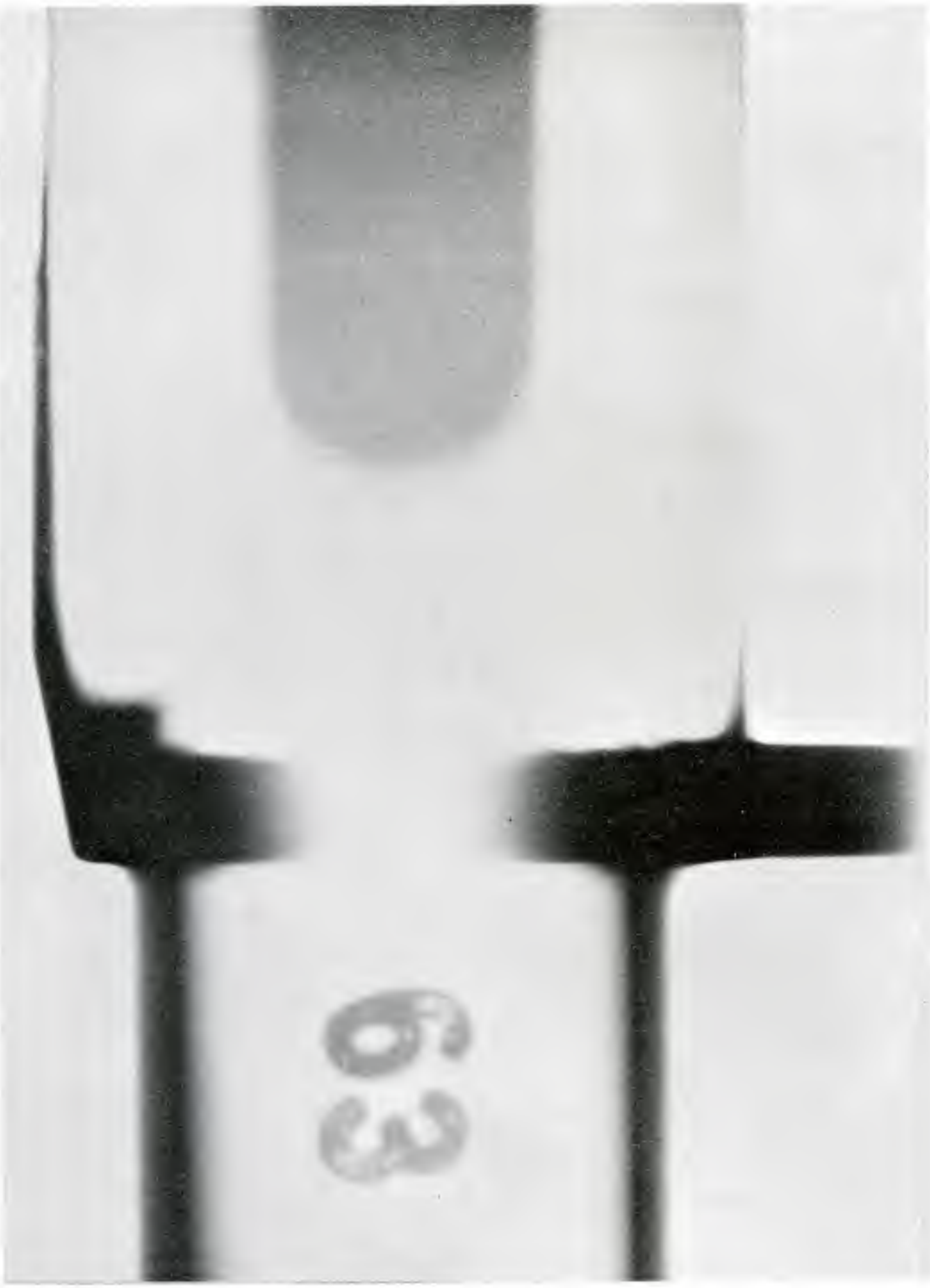


Figure 45

Print from Radiograph of Barrel Support Squeeze Casting Showing Excellent Quality thickness of the interface between the rectangular portions and the tubular portion. This gave rise to porosity at the interface as shown in Fig. 46, whereas such porosity did not occur in the previous castings with the double-acting type of operation. Attempt was made to remodify the punch support to minimize the increase in the section thickness, but this could not be adequately done and the squeeze castings continued to show some porosity in this area. In production such porosity can be avoided with a truly double-acting operation using a double-acting press.

The squeeze casting generally shows a fine columnar grain structure with the grains growing from the outside surfaces of the side walls and meeting at near mid-section. Such structure can be clearly seen in Fig. 47. As can be expected, since the melt is in contact with the lower die for a longer time and since the lower die comes in contact with the outside of the barrel-like portion of the casting, the grains growing from the outside of the wall are much longer than those growing from the inside. The grains are shortest at the corner of the punch where there must be much material movement as the punch is pushed down into the solidifying work material. The excellent surface quality of the casting can also be noticed, the only imperfection being at the top corner where there was some tearing because of the deformation of the carbon steel punch with which this particular casting was made.

7.3 <u>Mechanical Properties and Chemistry</u>

As in the case of the receiver base squeeze castings, the composition was checked on a number of barrel support squeeze castings; the resulting analyses are given in Table 13. As can be seen, no difficulty was encountered in achieving the target chemistry with only minor occasional variations. The tensile test specimens were cut once again directly from the squeeze castings and not from any specially made keel blocks as is common in sand casting foundries. A number of different conditions were utilized in terms of heat treatment, and the conditions as well as the resulting data are provided in Table 14. The comments in Section 6.3 for the receiver base also apply in the case of the mechanical properties of the barrel support. The only additional comment is that in a few cases the yield stress and the tensile stress values are somewhat lower because inadvertently the heat treatment selected was that for the lower specifications for the receiver base. Basically, it can be said that with proper control over processing and optimized work material and heat treatment, it should be possible to meet the desired mechanical property specifications.

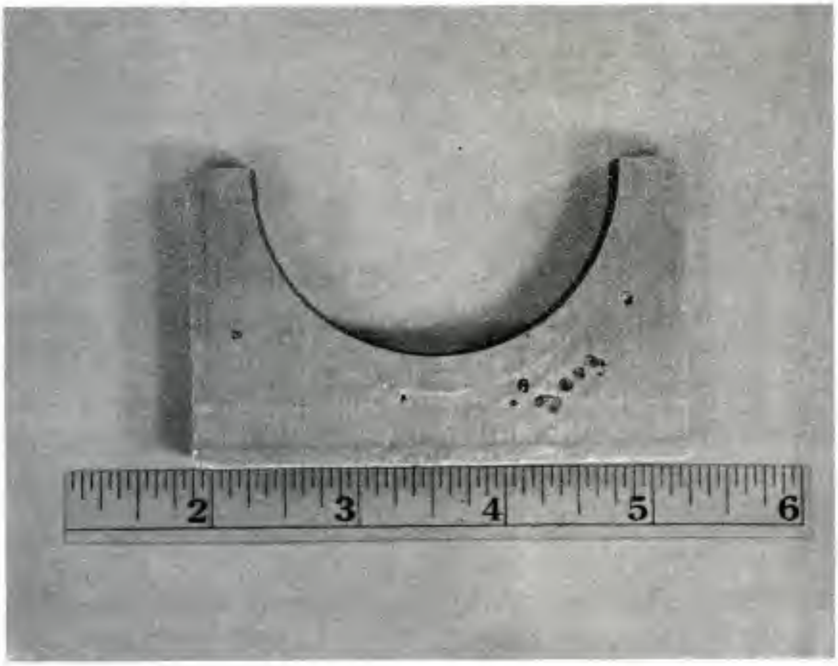


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Figure 46

Porosity at the Intersection of Rectangular and Tubular Sections of the Barrel Support (porosity occurred when the section thickness increased due to some part design modifications).

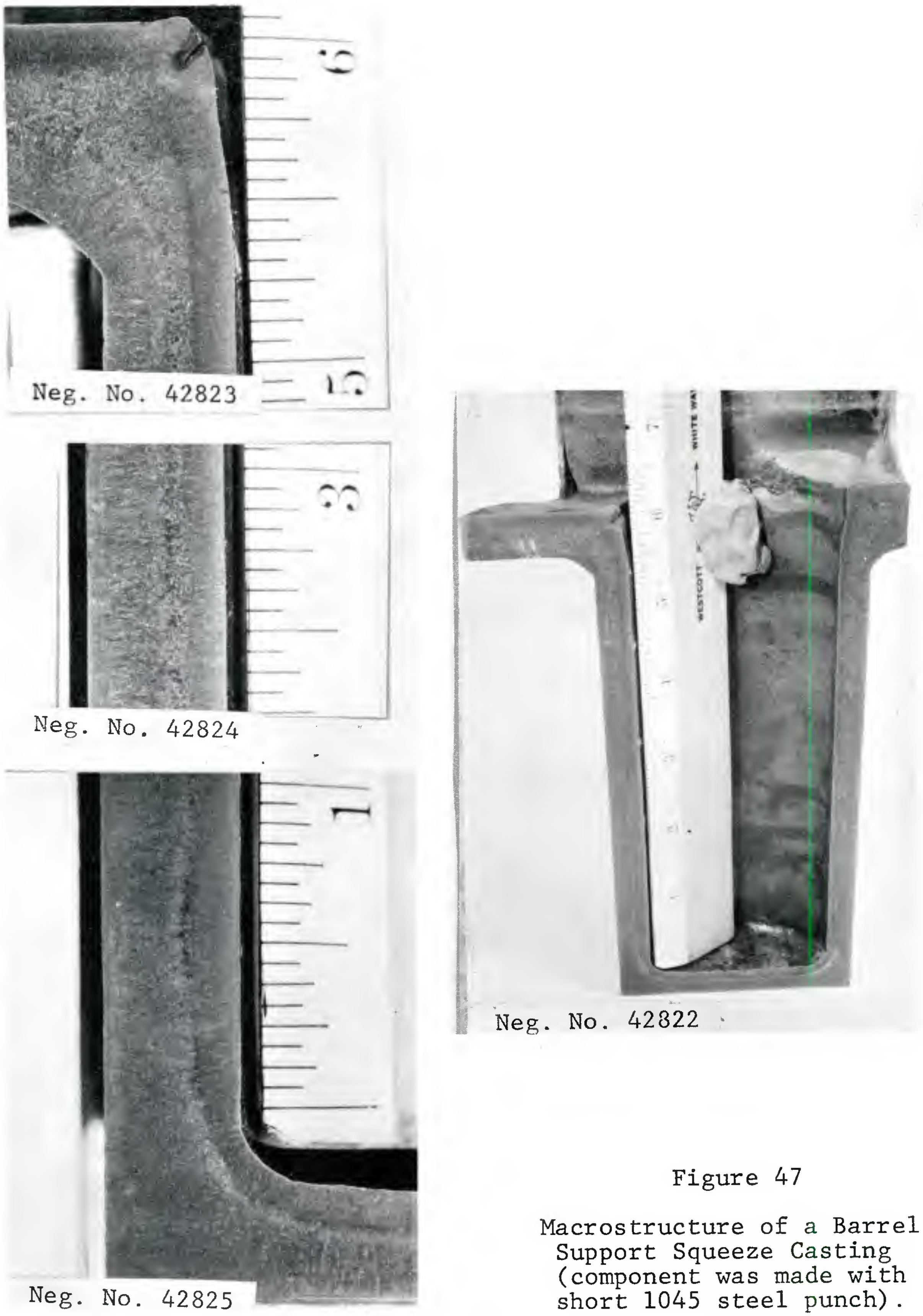

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Figure 47

Macrostructure of a Barrel Support Squeeze Casting (component was made with short 1045 steel punch).

Table 13

ANALYSIS OF COMPOSITION OF BARREL SUPPORT SQUEEZE CASTINGS

Identification	Composition, % C	Mn	Si	P	S	Ni	Cr	Mo
A17	.27	.66	.38	.015	.024	.63	.69	.55
32	.25	.68	-	-	-	-	-	-
33	.25	.69	-	-	-	-	-	-
35	.25	.66	.33	.016	.021	.51	.48	.56
36	.23	.67	-	-	-	-	-	-
116	.23 .22	.65	.28	.015	.032	.50	.42	.50
128	.30	.81	.56	.014	.026	.50	.54	.51
149	.22	.76	.45	.013	.024	.49	.51	.53
Typ. Sand Casting at RIA	.25	.75	.50	<.010	<.010	.50	.55	.55

Table 14

TENSILE PROPERTY DATA FOR BARREL SUPPORT SQUEEZE CASTING

Specimen Location	Hardness, R_C	YS (0.2% Offset), psi	UTS, psi	Elong., %	Reduction of Area, %
Tube Section	30	137,680	148,070	5	10
Tube Section	31	142,630	152,180	6	13
Rectangular Portion	34	146,120	155,420	8	14
Rectangular Portion	30	133,480	141,060	5	14

Notes:

1. Heat Treatment:

   Normalized at 1690°F for 1.5 hr.
   Austenitized at 1575°F and water quenched.
   Tempered at 1100°F for 1.0 hr.

2. Complete squeeze casting No. A58 heat treated and then specimens cut for testing.

3. Gage length 1 in., diameter 0.25 in. for tests.

4. Chemistry was 0.33% C, 0.47% Ni, 0.52% Cr, 0.53% Mo, 0.72% Mn, 0.35% Si, 0.015% P, 0.021% S.

5. The desired properties were 125,000 psi YS, 150,000 psi UTS, 9% elongation, and 22% reduction in area.

7.4 Comparison of Performance of Various Die Materials

All the main die components for both the barrel support and the receiver base die sets were made from H13 die steel and many of the die support elements were made from common hot rolled steel. The usage of these materials was very deliberate with the purpose of showing that even these common materials which are used in conventional forging dies will be suitable as die materials for squeeze casting. The subject work shows quite conclusively that, in spite of the complexity of the components investigated, the die steel and the hot rolled steel are completely satisfactory die materials. This is noteworthy since the overall sizes of die sets were considerably smaller than the size of the die blocks that are utilized in the dies for conventional forging. Additional details of the performance of individual components were given in Section 5.

The cylindrical portion of the punch for the barrel support die set--the punch pin--is the component that has to withstand the most severe service since it is a relatively small diameter, long length part that is completely surrounded by molten metal during squeeze casting and is also subjected to relatively high pressure. At the outset of the program, it was not clear whether any material can be found that would be satisfactory for long runs. Therefore, in the course of this project, the punch pin was made from a number of different die materials to compare their performance. The materials used were Anviloy, Inconel 718, Inconel 713C, and 1045 steel. The composition and some of the properties of these materials were given in Table 1.

The tungsten-base Anviloy was initially selected in view of its high strength at the high temperatures and its nonwettability with molten steel. However, this material, which is normally processed by powder metallurgy techniques, has poor ductility and poor resistance to bending stresses or impact. The punch pin appeared to give good surface finish on the castings and did not show local deformation. However, during the very first trial, the punch broke in two pieces and into more pieces in the next trial, showing that it was completely unsatisfactory for the application. (It may be recalled that when the same material was used as the punch material for the receiver base in a number of trials, some swelling appeared on the punch that gave unacceptable depressions on the squeeze casting.)

The Inconel 718 material was selected in view of its high strength at high temperatures and reasonable amount of ductility. There was some concern in using this material since it melts some 500° or 600° below the melt temperature used for the low alloy steel work material, but it was reasoned that if the surface of the material is adequately protected to prevent welding on contact with the molten work material, the heat transfer rate could be fast enough to prevent any melting of the material. The tests carried out supported this reasoning and Inconel 718 material performed completely satisfactory as a punch material. At the start of the series, the punch was coated with a glass-base material (see Sections 4.5 and 5.2), then carbon soot was built up on the punch before each squeeze casting trial. In some tests, when the punch could be retracted immediately at the end of the load release, the punch would appear red hot and yet it did not show any welding with the squeeze casting. The only deformation that was noticeable was on the lower corner of the pin which had a small initial radius of 1/4 in. Some minor local upsetting occurred that could be readily removed by hand-polishing. After this was done two or three times, the punch radius assumed a stable value and did not present any problem. In all, 64 squeeze castings were made with the first Inconel 718 punch before it was damaged due to malfunction of the press. The second Inconel 718 punch was utilized in 40 squeeze castings and is still in excellent usable condition. It is shown in Fig. 48.

Inconel 713C and 1045 type steel were used as punch pin materials and also to study the effect of punch geometry. Therefore, the length of the punches made with these materials was approximately 3 in. shorter than that made with the Inconel 718 punch. It was clear that the 1045 steel would be unlikely to survive a long squeeze casting series. However, it was included in the study to check if it would be satisfactory when only a few squeeze castings are to be made. Alternatively, in squeeze castings of even greater complexity, it could be used in certain locations as a disposable material that may last for only a few squeeze castings or perhaps--depending on the complexity and size of the part--even only one squeeze casting. In all, ten squeeze castings were made with the punch and, on the whole, it survived the series very well. The only noticeable deformation (Fig. 49) was at the top edge of the pin where it screws into a die steel punch body. It appears that this deformation occurred because a fine fin extruded into the clearance between the punch pin and the punch body and the abrasive action of this thin hard fin caused the softer 1045 steel pin to wear and deform in this region. The material certainly shows the potential for short runs or as a disposable item. Inconel 713C punch was used in 10 squeeze castings. It shows no deformation apart from a slight scraping caused during the initial die assembly and alignment operation. However, it

Neg. No. 42731

Figure 48

Inconel 718 Punch after Making
40 Squeeze Castings (the punch pin
is mounted in the punch support).

Neg. No. 42964

Figure 49

Local Deformation of the 1045 Steel Punch did suffer heat checking on the end face, Fig. 50. On the basis of the few tests carried out, it appears that the material may be usable but is somewhat inferior to Inconel 718.

The subject work has shown that the major die components for a squeeze casting die set can be made from common H-series die steels, the lower stressed supporting elements can be made from hot rolled steel, and the smaller components that are subjected to the severest service can be quite satisfactorily made from high-strength nickel-base superalloys.

7.5 Effect of Part Geometry on Quality

The barrel support and the receiver base are both thin-walled, long parts and yet represent somewhat different types of complexity. The barrel support is a very long, thin-walled part with a long, tubular section, and was squeeze-cast with a pressure application in the direction parallel to the axis. The receiver base is a long, thin part with "U"-like cross-section, and was made with its length in the horizontal plane. The versatility of the squeeze casting process is shown by its success in making each of these components in a single operation starting from the molten work material. Some additional part geometry features were studied by varying the geometry of the barrel support.

As mentioned earlier, punches from Inconel 713C and 1045 steel were made with a length 3 in. shorter than that of the Inconel 718 punch. In the trials with the shorter punch, the ejection pin height was increased so that squeeze castings 3 in. shorter in length were made. In the full-length squeeze castings, the wall thickness was typically only 0.35 in. and the length 14 in., corresponding to an extremely large height-to-thickness ratio of 40. In the squeeze castings made with the shorter punches, the length-to-wall thickness ratio was reduced to approximately 30. Since basically satisfactory squeeze castings were made even with the greater height, the effect of the lesser height was apparent mainly in the lower squeeze casting load required. Thus, whereas 150 tons load corresponding to 24,000 psi was inadequate for the full-height squeeze casting, the shorter squeeze castings could be made quite satisfactorily with the same pressure. Because of the combination of the shorter height-to-diameter ratio and the lower pressure, the requirements on the punch material are also less severe in the shorter squeeze castings. As mentioned in the previous section, 1045 steel could be used as a punch material for a few squeeze castings in the shorter run. It is possible that this material may have been unsatisfactory for the very long punch in the full-height barrel support.

Neg. No.43251

Figure 50

End Facing of the Inconel 713C Punch
Showing Heat Checking

Several other comments can also be made about the effect of part geometry on the basis of die modifications carried out in the course of this work. In the squeeze castings made in the first two series, many of the corner radii were very sharp (of the order of 1/32 in. or lower) since attempt was made to produce some of the surfaces net to the machining tolerances. Squeeze casting trials showed that in many cases cracking occurs in these sharp corners, and this would be readily eliminated by increasing the radius as was done during the later squeeze casting series. While conducting this modification, the various steps in the interior of the rectangular portion of the barrel support were eliminated and, inadvertently, the thickness of the interface between the cylindrical and the rectangular portions was increased as discussed in Section 7.2. This caused some porosity in this thicker interface whereas none existed in the squeeze castings made in the earlier series. It is felt that the porosity here resulted from the essentially single-acting nature of the die set. A double-acting die set or a larger auxiliary hydraulic cylinder should eliminate this porosity. However, it does point to the need to carefully analyze the section thicknesses in various areas of a component to be squeeze cast. Note that these comments refer to a relatively thick region connected by two thinner sections. Even with a single-acting die set, substantial variation in section thickness can be handled if the thicker portion occurs near one end of the squeeze casting. In fact, in some cases this may be advantageous since, with proper design of the component as a squeeze casting, the thicker section can be made to serve as a mini-riser.

In Section 7.1, reference was made to the hot tearing occurring in the tube-like portion of the barrel support when the squeeze casting shrank onto the punch because of the inability to open the dies as a result of the inadequate press retraction force. As mentioned in Section 5.2.3, the last few squeeze castings were made with a somewhat thicker wall in the tube-like section when some cleanup of the lower die to correct for accidental damage increased the tube outside diameter. The squeeze castings made with this larger diameter in the tube section were essentially free of hot tearing even when they shrank onto the hard punch. This points to one way of overcoming this problem in making complex components where the component geometry may necessitate usage of a hard punch on which the squeeze castings may shrink during processing.

The die modification shown in Fig. 27 points to yet another technique that can be employed to obtain a defect-free squeeze casting. In this case, because of the large variation in section thicknesses, some shrinkage porosity was expected and could not have been avoided except through some elaborate die system design. Therefore, instead of attempting to eliminate it completely, the part geometry was modified with only a minimum amount of additional machining so that the porosity, if it does occur, occurs in a region that is machined off during the finish machining operation. The finish-machined component should thus still be completely free of defects.

7.6 Effect of Process Variables on Quality

The effect of process variables has been discussed in various earlier sections and is summarized here with additional comments about certain special tests. Basically, the important process variables are the work material and die temperatures, delay time between introducing the metal into the die and applying pressure, the pressure level and its duration, and the mold separating agents.

For ferrous materials, the melt temperature can be varied over only a short region. If the melt temperature is high, it improves the surface finish of the component and can reduce the requirement for load, but it may adversely influence the die life and cause local welding between the die and the workpiece. Too low a melt temperature would, on the other hand, give a very coarse surface finish even when high loads are utilized. The delay time is of the order of only a few seconds in squeeze casting of thin-walled components and is best controlled by deciding on the proper value of the press speed settings.

In making the barrel supports, the melt temperature was in the majority of cases between 2900° to 2975°F and it was between 2900° to 2950°F for the receiver bases. The long, tubular shape of the die cavity for the barrel support die set would have made it extremely difficult to repair the die set in case of any local welding. Therefore, a conservative approach had to be taken in minimizing the possibility of such die damage. Additionally, at the low temperature range, there was the danger of excessive pressure buildup on the punch which would have caused barreling of the punch. Consequently, only a few experiments were tried at 2800°F melt temperature. These tests had poorer surface as was anticipated. With a few exceptions, the melt temperature was not increased beyond 2975°F. The range was too narrow to show any major differences in the products but the test with the melt temperature towards the upper values had, in general, good surface finish, Fig. 51.

Neg. No. 42729

Load, tons:	150	100
Melt Temp., °F:	2900	2800

Figure 51

Higher Temperature and Load Leads to a Better Appearance

The effect of die temperature is, in a way, analogous to that of the melt temperature. Higher die temperature would increase the tendency of local welding between the die and the work material, whereas too low a die temperature would lead to poorer surface finish and could increase the load requirement for proper die filling which could, in turn, endanger the tooling. The majority of the experiments in this series were conducted with temperatures in the range of about 550 to 750°F. The temperature was varied in this range in various tests but did not show any significant variation in the product quality. This indicates that the entire range was optimum.

A number of experiments were carried out to investigate the effect of squeeze casting pressure with the rest of the processing conditions held constant. It can be seen from Fig. 52 that, as the squeeze casting load increases, the surface appearance of the squeeze casting improves. Naturally, for any given application, an optimum combination of the melt temperature and the load should be selected to obtain good surface finish and internal integrity, Fig. 51. Usage of excessive load should be avoided since it can adversely affect the die life.

The effect of duration of load is mainly on the internal integrity of the casting. With 0 sec duration, the solidification is incomplete and leads to porosity. With the duration of load of the order of 5 sec as was used in most experiments, the improvement in the internal integrity continues until the solidification is completed. Beyond this point, any longer swell of the pressure is unprofitable and should be avoided since it can affect the die life adversely.

The mold wash is an important parameter since it influences the surface appearance of the squeeze casting and also the ease or difficulty with which the squeeze casting can be removed from the dies. With some protective coatings such as ceramic materials applied to the die cavity at the start of a series, the carbon soot which is applied before each squeeze casting acts as an excellent mold separating agent. This eliminates or minimizes any tendency of welding between the work material and the die and also gives an excellent surface finish on the squeeze casting as shown in Fig. 40.

In short, it should be emphasized that, in making any squeeze castings and especially the more complex types as studied in this work, attempt should be to optimize the processing conditions and overdependence on any one processing variable should be avoided in trying to improve the quality

Neg. No. 42962

Load, tons:	150	100
Melt Temp., °F:	2900	2900

Figure 52

Effect of Load on Appearance of Squeeze Casting of the casting. The technique does require proper selection of a number of different variables and reproducibility in their usage is essential for a commercial production at high rates. It is recommended, therefore, that a programmable controller be employed to obtain reproducible sequence and proper control over the important variables.

7.7 Potential for Cost Reduction

The factors contributing to cost reduction when the barrel support is made as a squeeze casting are the same as in the case of the receiver base, and the discussion in Section 6.4 is applicable in this case also. Once again, the cost reduction will derive mainly from the elimination of largely manual operations such as making and breaking of molds and trimming of risers and gates, elimination of costs associated with storage and handling of large quantities of patterns and molding sand, and reduction in the overall facility cost. The higher production rate capability of the squeeze casting process should also lead to substantial reduction in cost. Other factors contributing to cost reduction will be lower reject rate of the castings, lower machining cost, and reduction in cost of the work material required per component.

The potential for saving is much greater in the case of the barrel support than in the case of the receiver base because of the complexity of the former. Depending on the production quantities required, the receiver base could conceivably be made by machining from bar stock or by using conventional forging and then finishing. However, the substantially higher complexity of the barrel support would make it uneconomical to machine it from solid or to make it as a forging even at the relatively low and high ends of the production spectrum respectively. Casting is the only practical technique of making this component apart from the possibility of redesigning it and using joining techniques. As a sand casting, it is an extremely difficult part and does have a substantially high rejection rate. All these considerations point to a significant saving in the overall costs when the barrel support is made by the route of squeeze casting.

8. PRELIMINARY PROCESS SPECIFICATION

This specification is drawn up assuming that the recommendations made for improvement in the process, as discussed in the previous chapters and in Section 9.2, will be incorporated in the production facility that may be set up for squeeze casting the receiver base and the barrel support.

8.1 Receiver Base

The component will be made by the squeeze casting process applying the usual standards of control over processing common in any good foundry. The work material will be melted in a large furnace and then may be transferred in a separate holding furnace in somewhat smaller quantities. From there the metal will be transferred into the squeeze casting die set in appropriate quantities. In the following specification, first the procedure is specified and then more details of the processing are given. Important conditions are presented in Table 15.

Procedure

- Open the dies and form a carbon soot coating on all the die cavity surfaces and on the mating surfaces of the two die halves.
- Introduce the work material melt into the die.
- Close the dies, and build up and maintain the pressure for the desired duration.
- Then release the pressure and open the dies as soon as possible.
- Remove the stripper plate if the die design used does not make it a part of opening the die itself.
- Move the ejection pin up to lift the squeeze casting from the bottom die.
- Lift the casting off from the lower die and retract the ejection pin to the lowest position.
- Inspect the die cavity and, if any bare metal spots appear, coat them with a ceramic coating material. (Periodically, some die repair may also be needed depending on the actual condition of the dies.)

Table 15

OPTIMIZED CONDITIONS FOR SQUEEZE CASTING THE RECEIVER BASE

Melt Weight	13-13.5 lb
Die Temperature	600° to 700°F
Melt Temperature	2900° to 2950°F
Time from Start of Pour to Application of Load	6 sec (max.)
Press Speed	300-600 ipm
Load Cycle	125 tons for 30 sec
Auxiliary Ram Load	8 tons for 30 sec

Note: Depending on the draft on the dies and the number of ejection pins, the casting may have to be cooled for a few seconds prior to ejection to minimize bending during ejection.

Equipment

A hydraulic press will be used for the squeeze casting process. It should have a minimum of 250-ton pressing capacity and minimum of 50 tons each for ejection of the casting and retraction of the top die in opening the dies. The press should have a programmable controller for proper and repetitive sequence of all the operations. The free speed should be at least 300 ipm.

Work Material

The material for squeeze casting should be selected to meet the property specifications of Federal Specification QQ-681, Type 150-125. Previous experience shows that compositions similar to 8630 steel will be suitable.

Melt Temperature

The melt temperature in the melting and holding furnaces will depend on the melt transfer and handling facilities to be utilized. The temperature settings should be selected so that the melt temperature at the time of the introduction of the melt into the lower die is in the range of 2950° to 3000°F.

Die Temperature

The die temperature should be in the range of 500° to 700°F just prior to introduction of the molten work material into the dies.

Delay Time Prior to Application of Load

The time interval between the introduction of molten work material into the dies and the closing of the dies and application of pressure should be less than 10 sec. It can be controlled by activating the ram movement on introducing the metal into the die and selecting proper free speed.

Mold Wash

Prior to starting a squeeze casting series, an alumina-based ceramic coating should be applied to all the die cavity surface but not on the mating surfaces of the two die halves. The ceramic coating should be replenished if bare metal becomes apparent in the die cavity. In addition, carbon soot should be built up using oxygen-deficient oxyacetylene torch over the die cavity surface prior to each squeeze casting operation. The mating surfaces of the dies should also be coated with carbon soot or, if possible preferably with a graphite-base forging lubricant that leaves a dry film.

Forging Load

The forging load should be approximately 200 tons and should be maintained for 5 to 10 sec. After releasing the load, the top die should be retracted as soon as possible. Then the stripper plate should be removed if the die design has not made it a part of retraction of the top die itself. Then, the ejection pin should be moved up by the ejection system to lift the squeeze casting out of the bottom die. The casting can be removed from the dies manually or by mechanical means.

8.2 Barrel Support

The procedure and the specifications are, in general, similar to those for the receiver base as discussed in Section 8.1 The numerical values of some of the parameters are different. The important conditions for the barrel support are listed in Table 16 and the differences for the two components are obvious when compared with Table 15. In addition, the property specification for the barrel support is as per Federal Specification QQ-681, Type 150-125 instead of Type 140-115 for the receiver base. This casting is to be made with its length in the vertical direction whereas the receiver base is to be made with the length in the horizontal plane.

Table 16

OPTIMIZED CONDITIONS FOR SQUEEZE CASTING THE BARREL SUPPORT

Melt Weight	14.5-15 lb
Die Temperature	600° to 700°F
Melt Temperature	2950° to 3000°F
Time from Start of Pour to Application of Load	9 sec (max.)
Press Speed	300-600 ipm
Load Cycle[a]	200 tons for 5 sec then open dies immediately
Ejection Cycle	Remove stripper plate and eject immediately

[a]Depending on the component and die designs, usage of double-acting press may improve the product quality.

9. PRINCIPAL RESULTS AND CONCLUDING REMARKS

The foregoing sections have presented the details of the work conducted on squeeze casting of two large complex ferrous components, namely, the barrel support and the receiver base. This section summarizes the principal results and offers comments concerning the potential of the process for large-scale production of these weapons components. It is designed to provide an overall view of the capabilities of the process.

9.1 Accomplishments and Main Results

1. The technology of squeeze casting was advanced substantially and demonstrated by successful production of two complex ferrous components in material similar to 8630 composition which melts at a very high temperature range.

2. The barrel support is the most difficult component made thus far as a squeeze casting. The squeeze casting weighed only about 12 to 14 lb in relation to 80 lb weight of the corresponding sand casting with risers and gates, Fig. 53. Thus, the squeeze casting shows a very high material yield by comparison since the finish-machined component weighs only 7.4 lb. The squeeze casting has a thin wall of only 0.35 in., 14 in. overall length, and large height-to-wall thickness ratio of 40. This is completely beyond the capability of conventional sand casting or hot or cold forging techniques for this component geometry.

3. The receiver base component was successfully produced as a squeeze casting and weighed only 12 to 13 lb whereas the sand casting with risers and gates weighs 47 lb and the finish-machined component weight is only 6.2 lb, Fig. 54. Thus, once again, squeeze casting will have substantially higher material yield.

4. Tooling systems were designed and fabricated and showed to perform satisfactorily even when practically all the tooling was made from conventional hot work die steels. It appears that only the small punch pin for the barrel support need be made from a nickel-base superalloy and the entire system for the receiver base can be made from die steels.

5. The process parameters were optimized, and suitable die coating materials and techniques were selected to optimize the product quality. In particular, the surface finish was far superior to that of a sand casting or a conventional part forging.

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Figure 53

Comparison of a Machined Component, a Sand Casting, and a Squeeze Casting for the Barrel Support. (Note that the sand casting is shown in an orientation different from that during casting.)

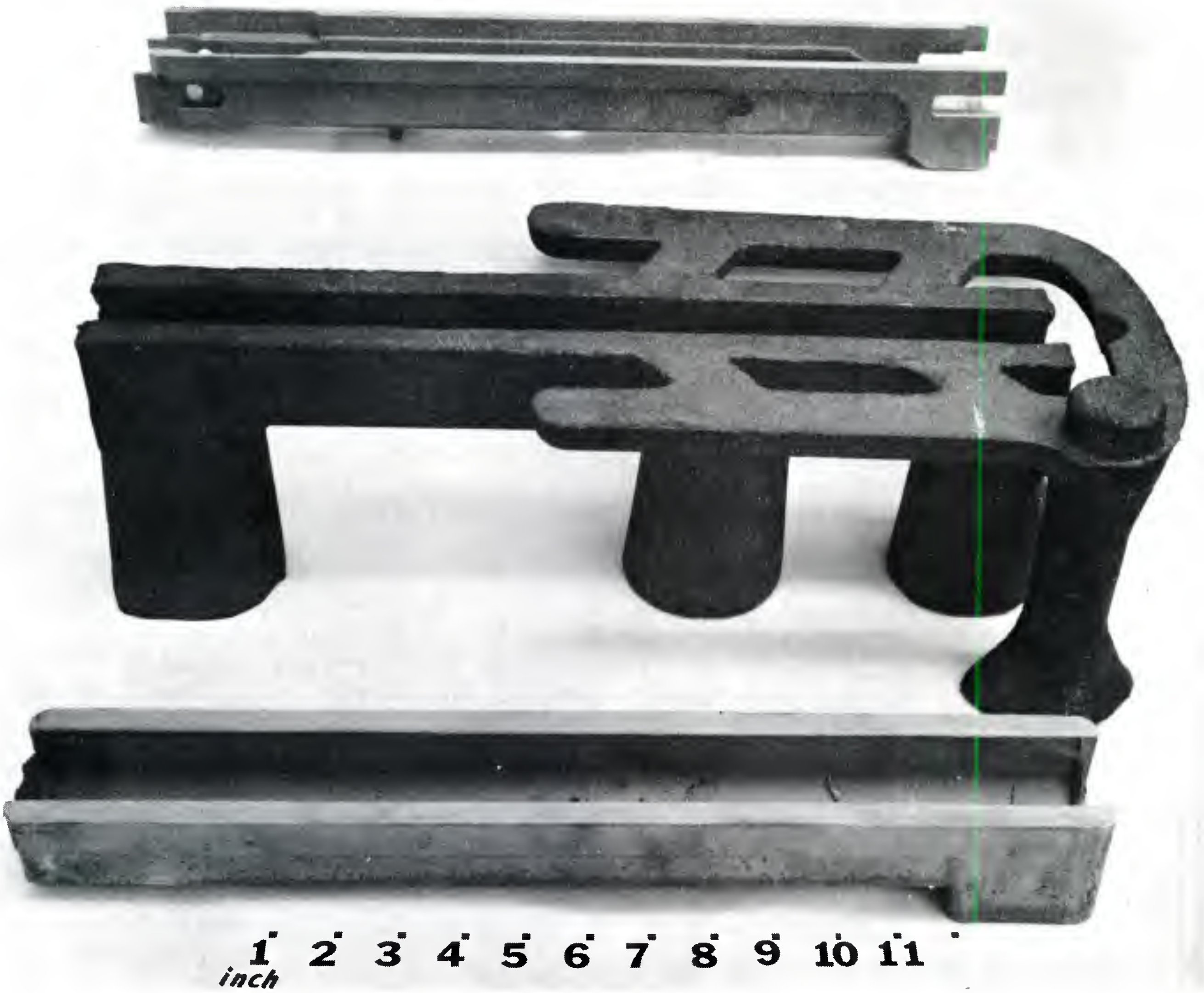

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Figure 54

Comparison of a Machined Component, a Sand Casting (center), and a Squeeze Casting for the Receiver Base. (Note that the sand casting is shown in an orientation different from that during casting.)

6. The receiver base could be made successfully even though the orientation was with the length in the horizontal plane and involved pouring the molten metal in a thin horizontal pool of 17 in. length.

7. For the first time, a specially designed auxiliary pressure application technique was used in producing a squeeze casting, namely, the receiver base. This technique was very effective in eliminating the porosity from the casting in spite of the large differences in section thicknesses of the various portions of the casting.

8. The castings were inspected radiographically and were also subjected to room-temperature tensile testing. With optimized process parameters, castings were made that were completely defect-free and met the room-temperature tensile property specifications. The reproducibility of these results was, however, less than desirable because of the limitations pertaining to this development program. In high rate of production, it should be possible to meet the specifications on a repetitive basis.

9. The work showed that in complex weapons components the squeeze castings will reduce the finish machining substantially, although some machining will be necessary when the final dimensional tolerances are of the order of a few thousandths of an inch.

10. The squeeze casting process shows potential for a substantial reduction in the overall cost of the finish-machined weapons components. Squeeze casting eliminates largely manual operations (such as mold making and breaking, and trimming of risers and gates) required in sand casting. There will also be substantial reduction in material handling and the equipment and space required in a sand casting foundry. The squeeze casting process will lead to higher material yield and the process has a much higher production rate capability. There will be significant reduction in finish machining and the rejection rate will also be decreased.

9.2 Comments on Large-Scale Production

1. The work conducted under the project indicates that the squeeze casting process is capable of production of even complex weapons components such as the barrel support and the receiver base at the production rates of the order of 2000 per year that are of interest to the Arsenal. Satisfactory production of complex weapons components will require close control over processing, which would indicate the need for programmable controllers or similar automatic controls.

2. The hydraulic press needed for squeeze casting is similar to a conventional forging press. However, some special features such as greater retraction force and higher ejection force capability may be necessary.

3. The duration of pressure is very short in the squeeze casting process and the production rate will be controlled mainly by the material handling capabilities of the squeeze casting system. With proper auxiliary equipment, a high production rate of the order of 1 to 2 per minute or 60 to 120 per hour will be possible even with a single unit. With several machines or a multiple-stage machine, the production rate can be even higher.

4. The lateral dimensions of the squeeze casting are dependent on the die dimensions and can be expected to be quite precise. The dimensions parallel to the direction of movement of the ram are dependent on the accuracy of the weight of the material enclosed in the die cavity. Hence, the squeeze casting system should be provided with proper melt metering facility or the die design should be such as to accommodate a reasonable amount of variation in the weight of the melt introduced into the die.

5. Practically all the die systems for squeeze casting can be satisfactorily made from common die steels. However, depending on the component geometry, some parts of the die are likely to be more susceptible to damage, especially when squeeze casting ferrous components. Therefore, the die design should be such as to allow easy replacement or repair of such components susceptible to damage. Better die materials with better properties could also be used for such components.

6. The squeeze casting process combines elements of conventional hot forging and casting techniques. Successful application of the technique will be dependent on properly training the personnel to familiarize them with the key features of the process. Some background in both conventional casting and forging would be valuable.

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Report R-CR-76-038, September 1976, p. 162, incl. illus and tables (Contract DAAF03-73-C-0099, AMS Code 3297.06.7257) Unclassified Report.

The project efforts described in this report demonstrate the feasibility of squeeze casting two specific steel weapon components -- the receiver base and the barrel support of the M85 Machine Gun. Squeeze casting is a hybrid of the conventional casting and forging techniques: molten metal is poured into a lower die cavity, and an upper die descends, displaces the liquid to fill the cavity, and compresses the confined

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Project efforts relate how molten, low-carbon alloy steel is vertically displaced through adjoining tubular and flat-walled columns and squeeze cast to form the barrel support. Auxiliary ram pressure applied in the die system for squeeze casting the receiver base, independent of the main ram pressure, effectively eliminates shrinkage in the abruptly thicker, last-to-freeze sections. Squeeze casting yields (ready-to-machine weight compared to melt-charge weight) for producing radiographically sound supports and bases exceed 90 percent, whereas conventional sand mold casting yields approach 30 and 45 percent, respectively.

The most favorable components to squeeze cast have compact, symmetrical designs without more complexity than a simple U-shaped cross section. Feasible designs are limited to those components which do not require molten steel to be displaced through thin, fast-freezing sections to feed adjacent sections before squeeze pressure is applied.

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